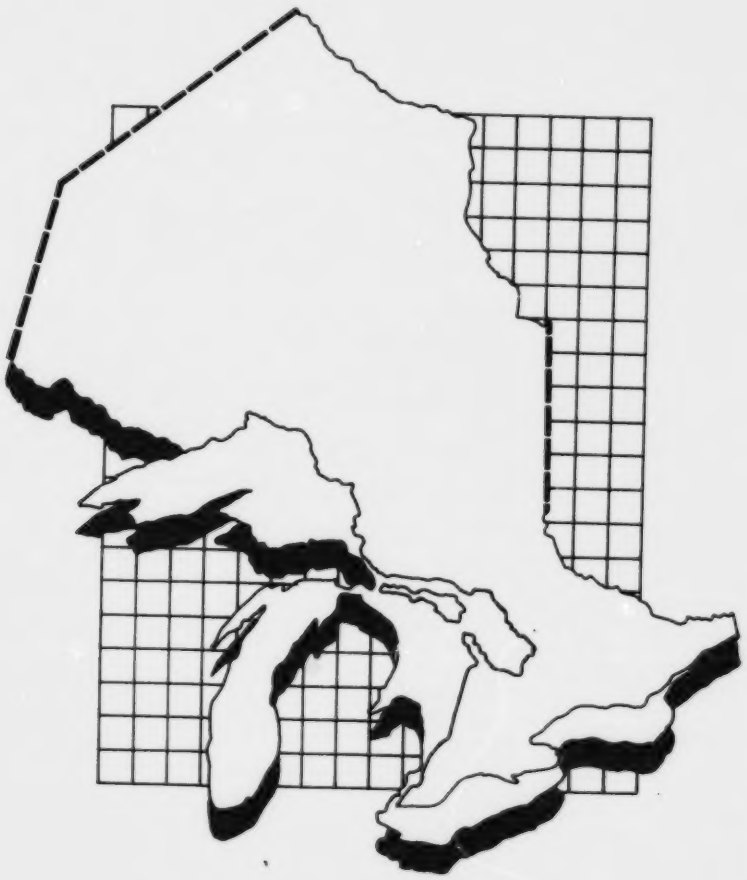
Landscape Planning for Energy Efficiency



Ontario
Ministry of Energy

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LANDSCAPE PLANNING FOR ENERGY EFFICIENCY

A state-of-the-art report prepared for the
Ministry of Energy

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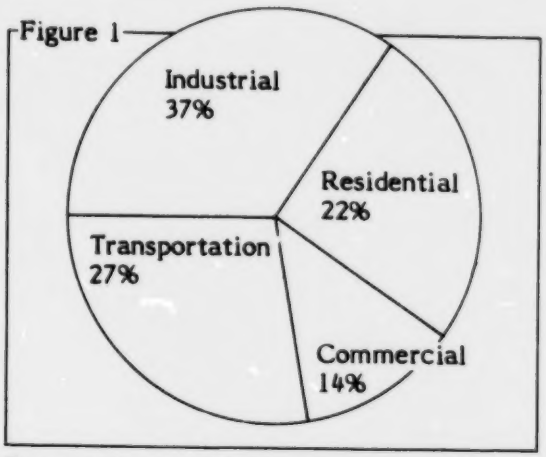
1.1 Energy and the Built Environment

During the last century and since 1945 in particular, Canada, along with the other industrialized nations, has developed lifestyles based on seemingly infinite supplies of cheap energy. Accompanied by rapid population growth and a tremendous increase in industrial output the resulting urban and rural developments were energy dependent in every aspect of construction and operation. The built environment now conforms largely to this pattern and as such consumes much of the energy used in Canada.

Figures on the distribution of energy use are instructive. The consumption of energy of all types in the various sectors in Ontario are illustrated in Figure 1 which shows residential use at 22 per cent of the total. Of this about 70 per cent is used for space heating.

Figure 1

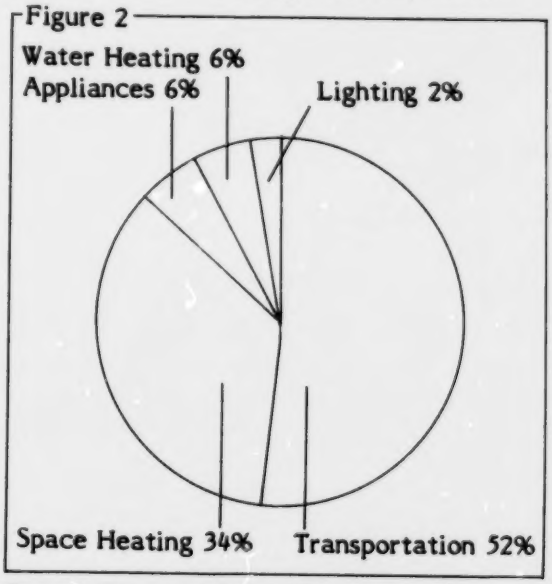


Energy Consumption by Sector
(Source: Ontario Energy Review, 1979)

Considered from a slightly different point of view allocating the part of the energy used in transportation to each family, Figure 2 results. Here it is seen that more than half of the total energy use is for transportation, much due to the family car. The recent dramatic changes in the availability and cost of energy demand that use patterns be reviewed and changes made to promote efficient use.

Energy efficiency is of particular importance in the fields of environmental design and community planning. The development of energy-efficient communities will require that current practices and lifestyles be significantly modified. To expect otherwise is to underestimate the relationships between energy, the physical environment and lifestyles.

Figure 2



Energy Consumption in Single Family Detached Dwelling
(Source: Energy Efficient Community Planning, P.7)

1.2 Landscape Planning for Energy Efficiency

Since energy is a fundamental component of Ontario life, energy efficiency must be the concern of all. In particular, the development of energy-efficient cities, towns and rural areas require the co-ordinated efforts of all the planning and design disciplines suppported by the financial, legal and technical institutions.

Within the process there is a significant role for landscape planners. In North America the belief in endless cheap energy has been exceeded only by the belief that the land itself was a limitless resource. To manipulate and consume this resource without regard for consequences, reduced landscape planning to a cosmetic and decorative activity without functional value.

In its broadest sense, landscape planning can be defined as the process of identifying, analyzing, and synthesizing those factors which determine the form and function of the exterior components of the built environment. It includes the planning and design of discrete exterior spaces, and also the arrangement, organization and planning of groups of buildings and the spaces defined by them.

The role of landscape planning in increasing energy efficiency covers two aspects of environmental design: reducing energy consumption in individual buildings and increasing the energy efficiency of the community as a whole. The planning and development of exterior spaces can reduce the energy consumption of buildings by reducing the adverse impact of some climatic factors while increasing the beneficial effect of others. These same planning activities should reduce dependence on energy intensive architectural spaces and modes of transportation. This can be accomplished by providing alternatives to artificially heated or cooled interior spaces in the form of climate controlled exterior space usable for longer periods of the year and accessible without the use of motorized transportation.

1.3 Goals and Objectives

It is hoped that this report will not only inform, but stimulate interest and discussion among professionals and the general public. It summarizes existing research information on landscape planning for energy efficiency and indicates those areas where further research is needed. Emphasis is placed on information applicable to the climatic and physical features which are typical of Ontario.

The technical aspects of landscape planning for energy efficiency are relatively straightforward and in many cases have been tested throughout the world for centuries. The novel requirement is a design commitment which can derive only from a recognition of the need for action and an understanding of the problem.

Objectives of the report include:

An identification of the specific characteristics of Ontario's climate and an analysis of their effects on energy consumption and human comfort.

An analysis of how the effect of climate factors can be modified by appropriate planning and design.

An analysis of the costs of landscape planning relative to its benefits.

1.4 Scope

Landscape planning for energy efficiency encompasses virtually all aspects of Landscape Architecture. In this report emphasis is placed on those aspects directly associated with the costs of heating and cooling buildings. While landscape planning can influence the energy component of construction and maintenance costs, detailed consideration of these is reserved for subsequent study. Consideration is given to both urban and rural development and to a range of building functions including residential, commercial, and industrial with emphasis on residential development within urban areas.

The report is necessarily limited by the availability of technical information based on research relevant to Ontario. Because much of the current work is being done elsewhere not all the results are applicable here.

1.5 Report Organization

Part 1: Introduction

Part 2: Climate of Ontario.
- discusses the climatic factors which affect energy consumption in Ontario and

describes the basic climatic patterns characterizing the province.

Part 3: Vegetation of Ontario.
- describes the major natural vegetation types found throughout Ontario and discusses their potential implications for energy-efficient design in various regions.

- discusses the climatic and physical factors which impose restrictions upon the importation of non-native plant materials to certain parts of the Province.

Part 4: Methods and Techniques.
- discusses the modification of climatic factors caused by terrain, vegetation, water bodies, and urban areas and describes the methods currently available for modifying the individual climatic factors.

Part 5: Integrated Methods and Techniques.
- discusses certain problems and conflicts which arise when combinations of climatic factors are considered together; emphasis is placed upon the application of climate control methods to a range of building, community, and open space types.

Part 6: Costs and Benefits.
- describes the parameters and methods of cost/benefit analysis and discusses available research concerning the costs and benefits

- considers those few factors whose direct effects can be traced and connects these with measurable benefits of landscape planning for energy efficiency as well as its value relative to other design disciplines.

Chapter 2

CLIMATE OF ONTARIO

2.1 Introduction

The climate of a given place is an abstract concept referring to the sum total of all meteorological phenomena. It is a major determinant of energy consumption in buildings. The departure of ambient temperatures from the levels acceptable to people, the degree of exposure to wind, the amount of sunshine determined by latitude and by cloud cover, all influence energy use.

Climate can refer to the average meteorological condition over a country or even a continent (1) and may then be referred to as the 'macroclimate'. The 'mesoclimate' refers to the area in which conditions are influenced by local geographical features while 'microclimate' is the term used to define the immediate climatic envelope surrounding people or buildings. Microclimates are determined to a significant extent by the physical environment to which they refer (2).

Because of the relationship between climate and energy use, energy-efficient design requires a detailed knowledge of local climatic conditions. The most important of these relate to temperature, wind and precipitation. With regard to each the the planner needs a knowledge not only of mean annual values but maxima and minima and diurnal variations. To be of maximum benefit, the scale of information must match the scale of the planning. That is, for detailed design one wants microclimatic not macroclimatic information. Although there is a wealth of data (3) from some 400 locations around the province, it is only during the past decade that it has been prepared and distributed for energy efficient planning and design.

In Canada, climatic data is collected, collated, and distributed by the Atmospheric Environment Service (AES) of the Department of the Environment. Available in both chart and map form, (see Figures 3-6) data is available on each of the

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(1) Geiger, p. 3
(2) Laidlaw, p. 14
(3) The Tourist and Outdoor Recreation Climate of Ontario, p. 5

individual climatic factors and variables (4). At the present time, AES is involved in the preparation of a merged solar and meteorological data base which will provide information on the integrated impact of relevant climatic factors on energy consumption (5). The National Research Council has also been active in interpreting the raw climate data into forms which are useful for planners and designers. This information has been published as a supplement to the National Building Code of Canada (6). In addition, to these sources, synopses of Ontario's climate have been prepared by the Meteorological Branch of the Department of Transport (now AES). These include - The Climate of Southern Ontario and The Climate of Northern Ontario (7). The following comments and information have been derived from all of these sources.

2.2 The Climatic Conditions of Ontario

2.2.1 Climatic Controls

The macroclimate of Ontario is classified as modified continental. A continental climate is characterized by cold winters and warm summers and generally has more precipitation in summer than in winter. However, beyond these very general characteristics, the climate of Ontario varies considerably across the province. This variability is caused by latitude, physiography, water bodies, and weather systems. These factors are briefly discussed below and will be considered in greater detail in Part 4: 'Methods and Techniques'.

---

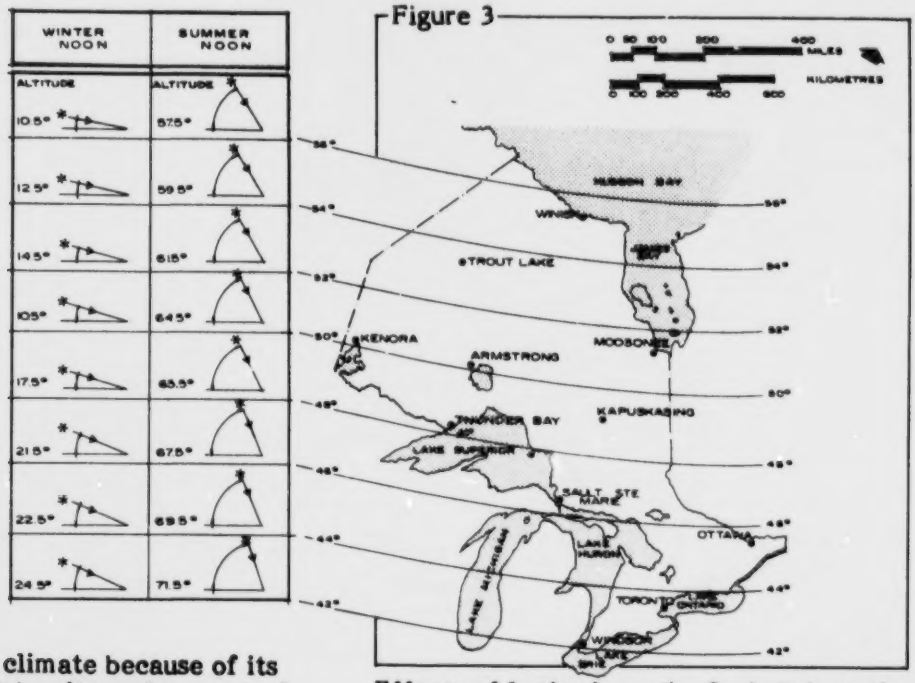
(4) Climatrological Atlas of Canada, Canadian Normals.

(5) Define, Develop and Establish a Meteorological Computer Data Base, 1980.

(6) Climatic Information for Building Design in Canada, 1977.

(7) The Climate of Southern Ontario, 1980.
The Climate of Northern Ontario, 1968.

Figure 3

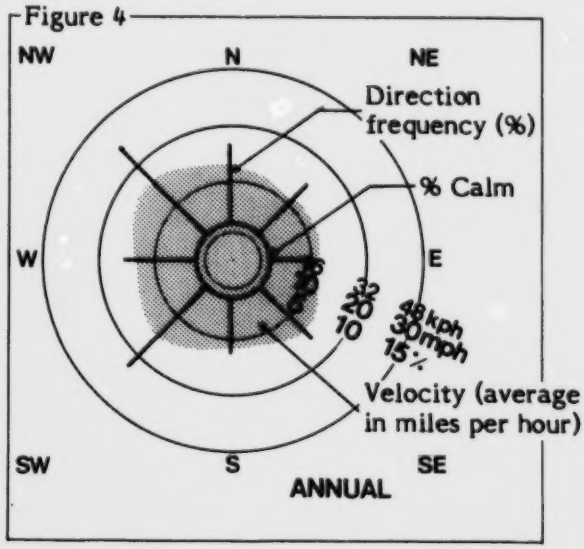


Effects of Latitude on the Sun's Orientation

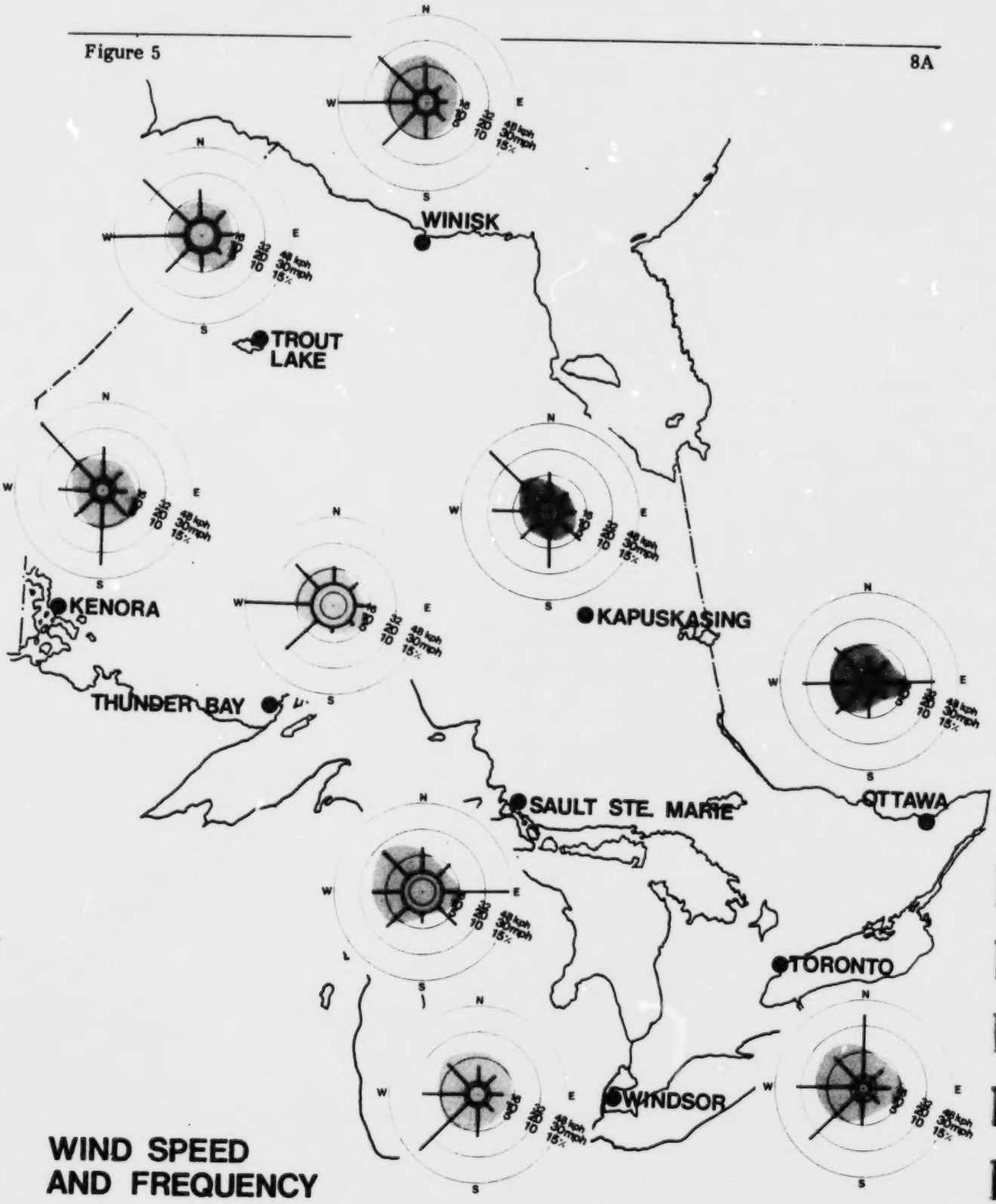
Latitude influences climate because of its relationship to the intensity and amount of solar radiation. The angle of incidence of the sun at noon at various latitudes in Ontario is shown for winter (December 21) and for summer (June 21) in Figure 3. The low angle at high latitudes reduces the intensity of solar radiation on horizontal surfaces, particularly during the winter when the length of time the sun is above the horizon is also reduced. Thus, the warming effect of the sun is much lower in the north than the south although this is influenced locally by cloud over.

Wind - The wind is a very important factor in energy efficient design due primarily to its effect on heat loss during the winter. Wind in summer is beneficial and can help reduce the amount of energy required for cooling. There are three variables necessary to describe wind activity at any one location: direction, velocity, and frequency. Because of the interrelated nature of these variables, it is necessary to display wind data in a way which expresses each variable in terms of the others. For this reason, wind data cannot be adequately displayed in map form. It is, therefore, more descriptive to use a wind rose, Figure 4.

Figure 4



The wind roses presented in Figure 5 for nine different locations demonstrate the variability of winds throughout Ontario. For January they show that in winter when wind infiltration in buildings is more critical winds are generally slightly stronger than in July and there are variations in direction from place to place. Also, it should be noted that the most frequent winds are not necessarily the strongest. The variability of winds shown illustrate the impossibility of identifying prevailing winds for the province as a whole or even, considering seasonal changes, for specific regions.

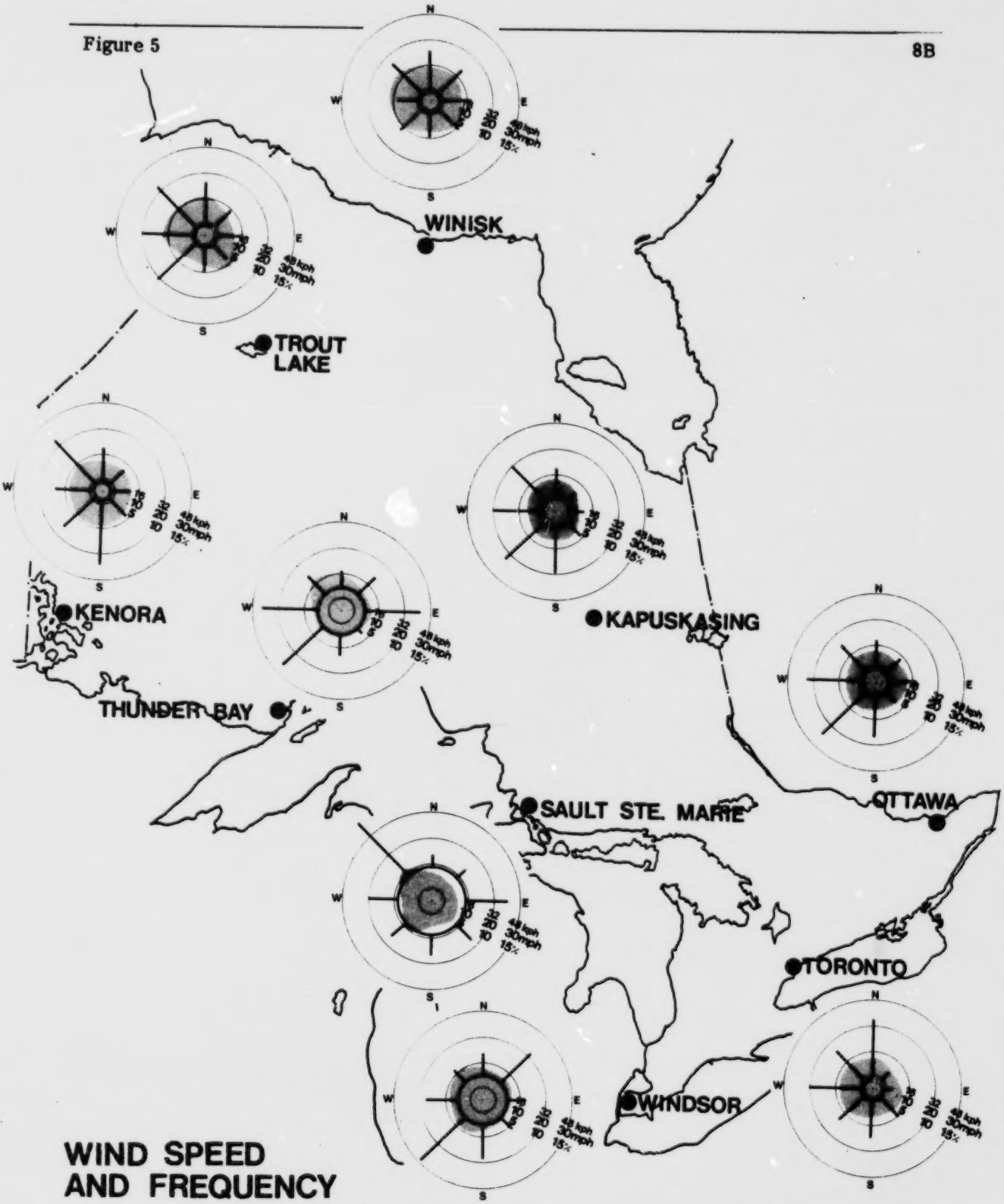


WIND SPEED AND FREQUENCY

0 50 100 200 400 MILES

0 100 200 400 600 KILOMETRES

JANUARY

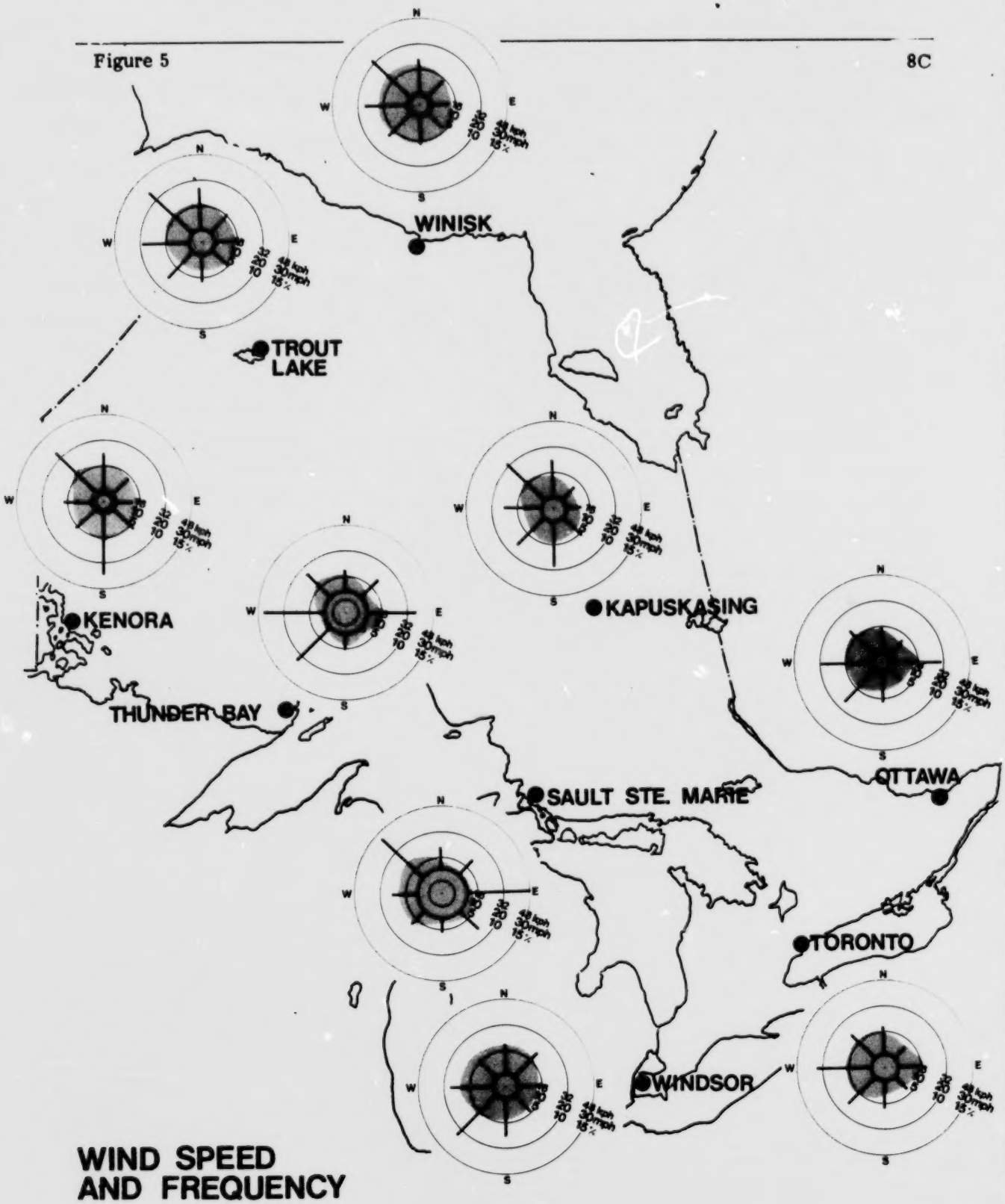


WIND SPEED AND FREQUENCY

0 50 100 200 400 MILES

0 100 200 400 600 KILOMETRES

JULY



WIND SPEED AND FREQUENCY

0 50 100 200 400 MILES

0 100 200 400 600 KILOMETRES

ANNUAL

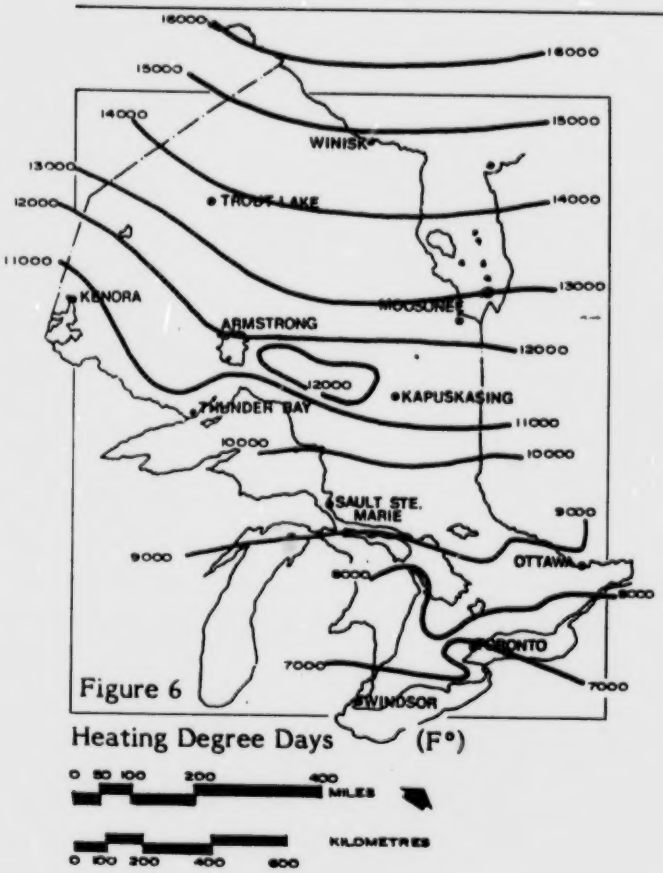


Figure 6

Heating Degree Days (F°)

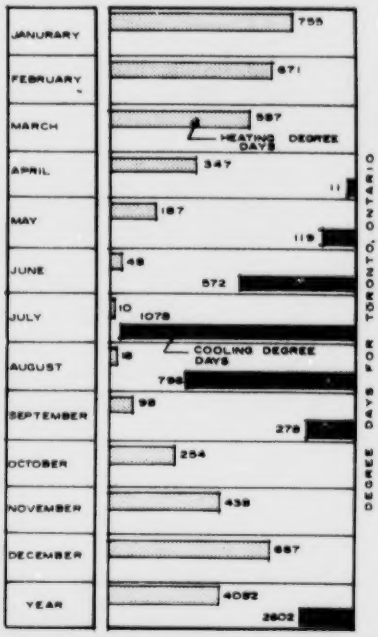


Figure 7

Heating/Cooling Degree Days (Toronto)
(Source: D'Agostino, p. 17)

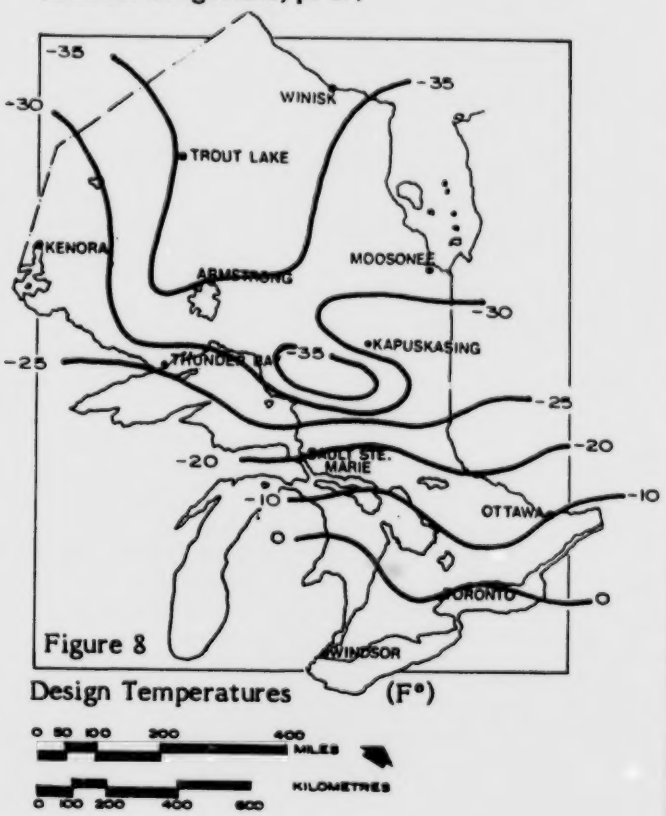


Figure 8

Design Temperatures (F°)

Air Temperature - Due to its critical relationship to both human comfort and energy consumption, air temperature is one of the most important climatic factors. Air temperature data is usually quite comprehensive and includes maxima, minima, means, and degree days as they relate to design temperatures are the most important. Typical data is shown in Figures 6-8.

Heating degree days are calculated by totalling the difference between 18°C and the daily mean temperature for every day of the year when the mean temperature is below 18°C.

Cooling degree days calculated from 24°C are less important for Ontario. Figure 7 prepared for Toronto shows that in a typical year there are almost twice as many heating as cooling degree days and this ratio would, of course, be greater in the northern part of the province.

Design temperatures are the minimum temperatures for which the building's heating system should be designed. Based on a number of technical criteria, design temperatures are higher than local minimum temperatures which are usually infrequent and not of long duration.

Humidity - Humidity refers to the amount of water vapour present in the air in a gaseous form. Since warm air can contain more water vapour than cool, humidity is usually expressed as relative to the maximum which could be contained at a particular air temperature. Thus, a given relative humidity has a specific meaning in terms of mass of water vapour per unit mass of air at only one temperature.

In Table 1 below, the relative humidity is given for several Ontario locations for each of the four seasons. Note that the relative humidity is highest in the winter.

Another means of expressing humidity is in terms of the mixing ration which gives the number of grains of water vapour per pound of air (a grain is one-seven-thousandth of a pound). Table 2 shows this mixing ratio is lowest in winter. This explain why the indoor relative humdity is low in winter; as the cold air containing very little moisture is warmed, its capacity to hold moisture rises.

Mean values of relative humidity based on daily readings taken at 0130, 0730, 1330 and 1930 Hours (1941-1950)

(Source: The Climate of Northern Ontario, P.11)

Table 1

Station	Dec., Jan., Feb.	Mar., April, May	June, July, Aug.	Sept., Oct., Nov.
Winnipeg	88	72	68	76
Armstrong	91	73	73	85
Earlton	90	75	75	82
Fort William	84	77	78	81
Kapuskasing	88	72	73	83
Kenora	91	68	71	81
Lansdowne House	89	75	74	83
Moosonee	85	76	74	82
Nakina	93	71	74	86
North Bay	88	70	76	82
Pagwa	90	71	71	84
Sioux Lookout	92	67	72	82
Trout Lake	86	79	77	85
Porquis Junction	92	74	70	83
Toronto (Malton)	82	72	70	79

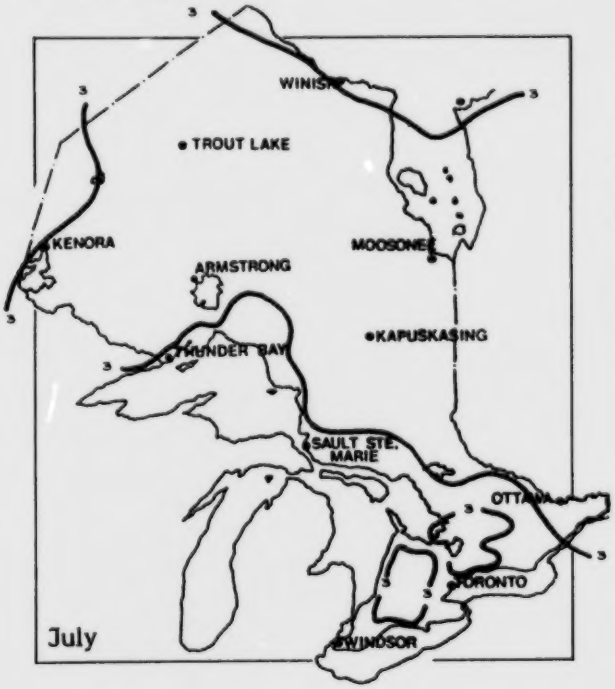
Table 2

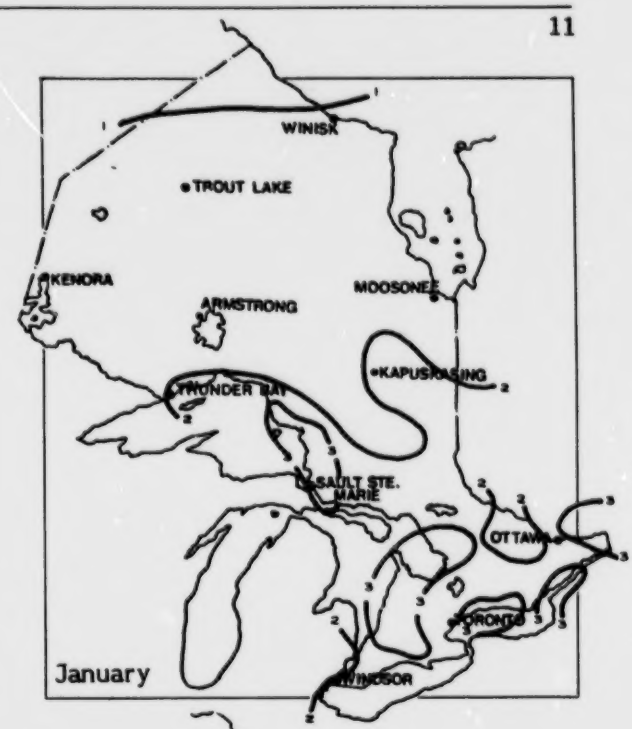
Location	*1941-1960*											
	Jan.	*Feb.*	*Mar.*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
Ottawa	9	10	16	26	42	63	73	70	54	36	23	13
Windsor	17	16	23	33	48	74	84	83	65	44	30	20
North Bay	8	10	14	22	38	58	70	66	52	35	22	12
Toronto	15	16	19	28	41	62	75	74	57	41	28	18

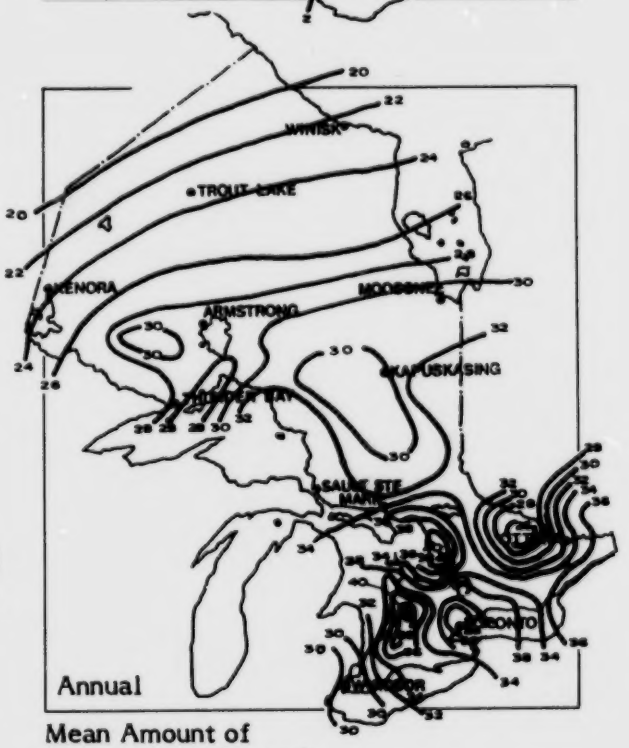
Mean Monthly Mixing Ratio (Grains/lb.) (Source: The Climate of Southern Ontario, P.57)

Precipitation - Precipitation includes rain, snow, hail, dew and frost. Of these, rain and snow are the most important in terms of energy efficient design. The amount of total precipitation tends to decrease as one moves from regions adjacent to the Great Lakes where high rainfalls are general. The distribution is shown in Figure 9. The fraction of the total which falls as snow, shown in Figure 10 is highest in the areas east of Superior and to the southeast of Lake Huron.

Thunderstorms tend to occur less frequently in nothern Ontario than in southern Ontario and are much more common in summer than in winter. The frequency in southern Ontario is due to the influence of the Great Lakes which cause movement of warm air masses from the tropics. Thunderstorms are also quite frequent in the Rainy River-Kenora district and are responsible for many of the forest fires in that area.







Mean Amount of Precipitation (inches)

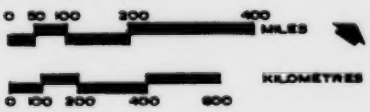


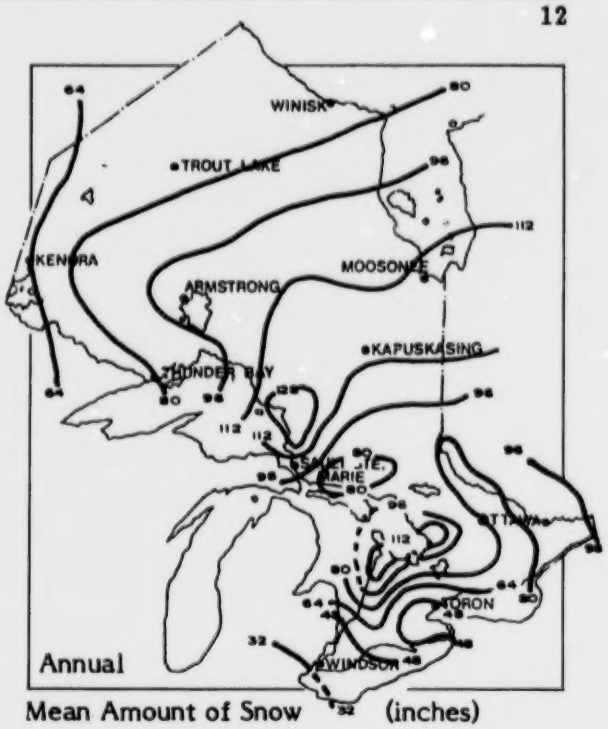
Figure 9

2.3 Priorities for Energy-Efficient Design

As indicated by the data of Figure 5, the climate of Ontario is characterized by warm summers and cold winters and as shown by Figure 6 there are many more heating than cooling degree days. This is even more true in northern Ontario as there are more than twice as many heating degree days there than there are in the southern part of the provinces. Consequently, the main concern in planning for energy efficiency in Ontario is the modification of those climatic factors which affect energy consumption in winter.

The climatic factors which are the most important for energy-efficient design in Ontario are the sun and the wind. Throughout the province there is some potential for solar heating as shown in Figure 11, especially in the southern half. Although the amount of solar radiation is reduced in northern Ontario, due to the sun's low angle of incidence, the sun's rays can penetrate more deeply into the interior of the building, thus enhancing their effect. Since winter wind speeds are relatively similar in all parts of Ontario, wind control is a necessity throughout. However, it must be noted that the direction of the prevailing winds will vary from place to place and that, in many locations, the winter winds may come from any direction with high intensity.

Precipitation control for energy efficiency should be given a high priority particularly in southern Ontario and in the regions boarding the Great Lakes. In two regions (east of Lake Superior and southeast of Lake Huron/Georgian Bay) snowfall is particularly heavy, as Figure 17 shows, and requires special consideration in environmental planning and design. Alternative methods and techniques for precipitation control are discussed in Section 4.



Mean Amount of Snow (inches)

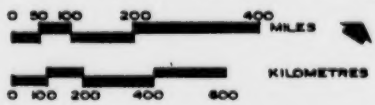
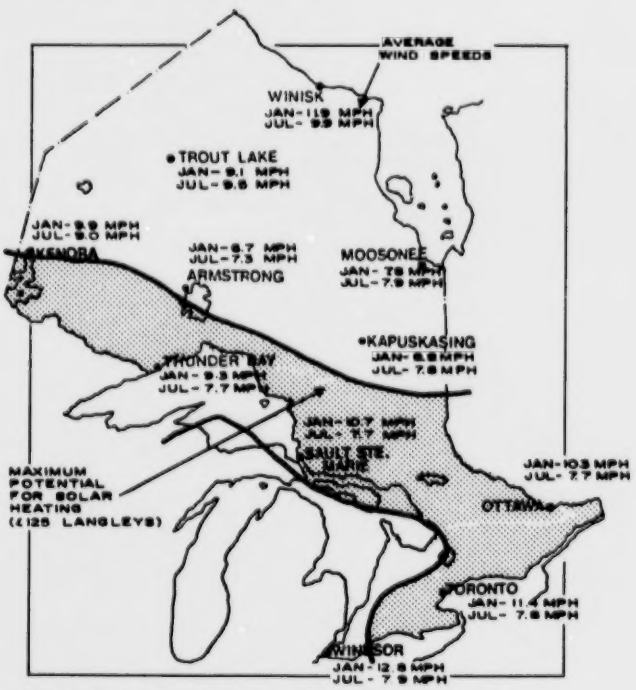


Figure 10



Priorities for Energy Efficient Design

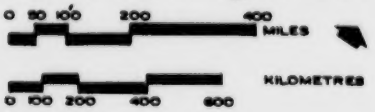


Figure 11

3.1 Introduction

Although there are many different kinds of materials which are used in landscape development, vegetation is of central importance. Important for both wind control and shade production, vegetation is considered throughout all stages of the planning process.

There are two different classes of vegetation which are of significance to landscape planning for energy efficiency. "Natural" vegetation includes the plants and plant communities which characterize a specific region and which may exist on an undisturbed site. While existing vegetation is usually valuable from many points of view (ecological, aesthetic, economic), it is particulary important in terms of energy efficient design; depending upon its extent, density, height, and form, existing vegetation can be a prime determinant of both site selection and site planning and design. "Imported" vegetation includes plant materials which are brought from other locations and installed on the site. Imported vegetation can include both native and non-native plant materials. Although they are frequenly used as they are found in their natural habitats, native plants can be selectively bred for specific traits. Non-native plants are plants from other regions, countries, or even continents.

Because plants are living organisms, they have specific environmental requirements which must be met in order to ensure survival. These impose restrictions upon the kinds of plant materials which can be used, consequently, it is important that Ontario be analyzed in terms of both natural vegetation types which characterize each region and the non-native plants which can be imported. In this section, a brief discussion of the main factors determining range of major plant communities is followed by a review of hardiness criteria.

3.2 Factors Affecting Vegetation

The type of vegetation characterizing a given region is the result of a process of evolution involving the dynamic interaction of many factors. Plants and plant communities develop in response to certain environmental factors, and also modify those very factors over time, thus permitting the survival of new plants.

Gradually a dynamic balance is established at which point the rate of evolution is reduced and change follows a cyclical rather than a linear pattern. (1)

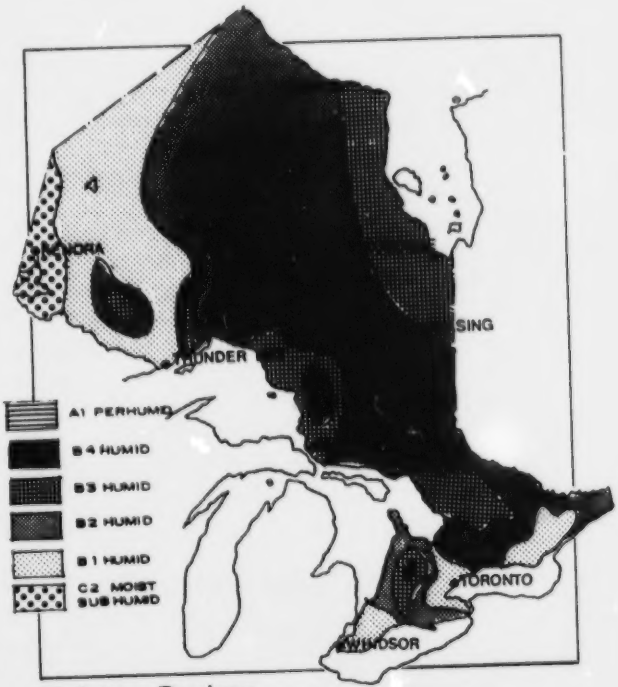
Climate - The climatic factors with most influence on vegetational type are temperature and precipitation. These determine to a large extent the species which will be involved in the cyclic evolution referred to above. A convenient unit of temperature measurement in this connection is the 'growing degree day' as mapped in Figure 12, which shows the total of degree days above 6°C. (2)

It is less easy to relate precipitation and vegetation. The time of year when the precipitation occurs, the nature of the soil and the topography all have an effect. For a given location it is possible to calculate the water surplus as the amount of precipitation in excess of that required to saturate the soil. The water deficit is the shortfall of precipitation from the amount of water deficit is the shortfall of precipitation from the amount of water assumed to be consumed by vegetation and released to the atmosphere. The deficit and surplus can then be combined to provide a "moisture index" which gives an indication of the relative aridity/humidity of a region (3). The moisture regions of Ontario are mapped in Figure 13.

As the accompanying map indicates, all of Ontario enjoys an annual surplus of moisture, the lowest surpluses are in scattered locations along the north shores of Lakes Erie and Ontario and along the southern parts of the Manitoba/Ontario boarder. The highest surpluses are in the lee of the Great Lakes and along the west coast of James Bay.

Growing Degree Days

Figure 12



Moisture Regions

Figure 13

(1) Forest Regions of Canada, p. 2
(2) The Climate of Southern Ontario, p. 36
Origin, Classification, and Use of Ontario Soils, p. 17
(3) The Climate of Northern Ontario, p. 10
The Climate of Southern Ontario, p. 54
Forest Regions of Canada, p. 155

Physiography and Soils - The physiography of a region relates to energy efficient landscape planning largely by reason of its relationship to soil formation, and therefore, to the vegetative cover which the soil will support. Soil, varying in depth from a mere film to several feet, has developed from the un-consolidated material. This in turn is composed of fragments of the underlying bedrock and of materials which were transported and deposited through glacial action (4).

The present physiography of Ontario is to a large extent the result of interaction between the basic bedrock formation and glacial activity. During the Pleistocene epoch, there were at least four invasions of ice, each separated by interglacial periods lasting many thousands of years. The latest period of glaciation (Wisconsin) completed its recession approximately 10,000 years ago and was the major influence upon the landforms now characterizing much of the province. This influence was due to the scouring and crushing action of the glacier and to the deposition and sorting of various materials when the ice sheet was melting. These latter materials include various mixtures of stones, gravel, sand, silt, and clay. In Table 3, the major physiographic regions of Ontario are described and are shown in map form in Figure 14.

The development of soil involves the differentiation into layers of soil horizons by four main processes. These are the addition of removal of chemicals and minerals, the chemical transformation of constituents, the translocation of particles from one layer to another and the formation and accumulation of organic material. All of these processes are interactive and on-going so that the life of a soil is one of constant evolution (5).

Table 3

HUDSON BAY LOWLAND Unconsolidated glacial and post-glacial deposits underlain by Palaeozoic limestone over Pre-cambrian rock; poorly drained, abounding in bogs, shallow lakes.
CANADIAN SHIELD Precambrian rock (largely granite, quartzite and other siliceous rocks) covered with a shallow layer of stony sandy till; knob and ridge topography (500-2,000 feet elevation) with an extensive network of streams, lakes, ponds, bogs and localized lacustrine clay deposits.
GREAT LAKES - ST. LAWRENCE Plain, gently sloping Palaeozoic dolomite, sandstone, limestone and shales overlain by deep glacial till and post-glacial lacustrine and alluvial deposits.

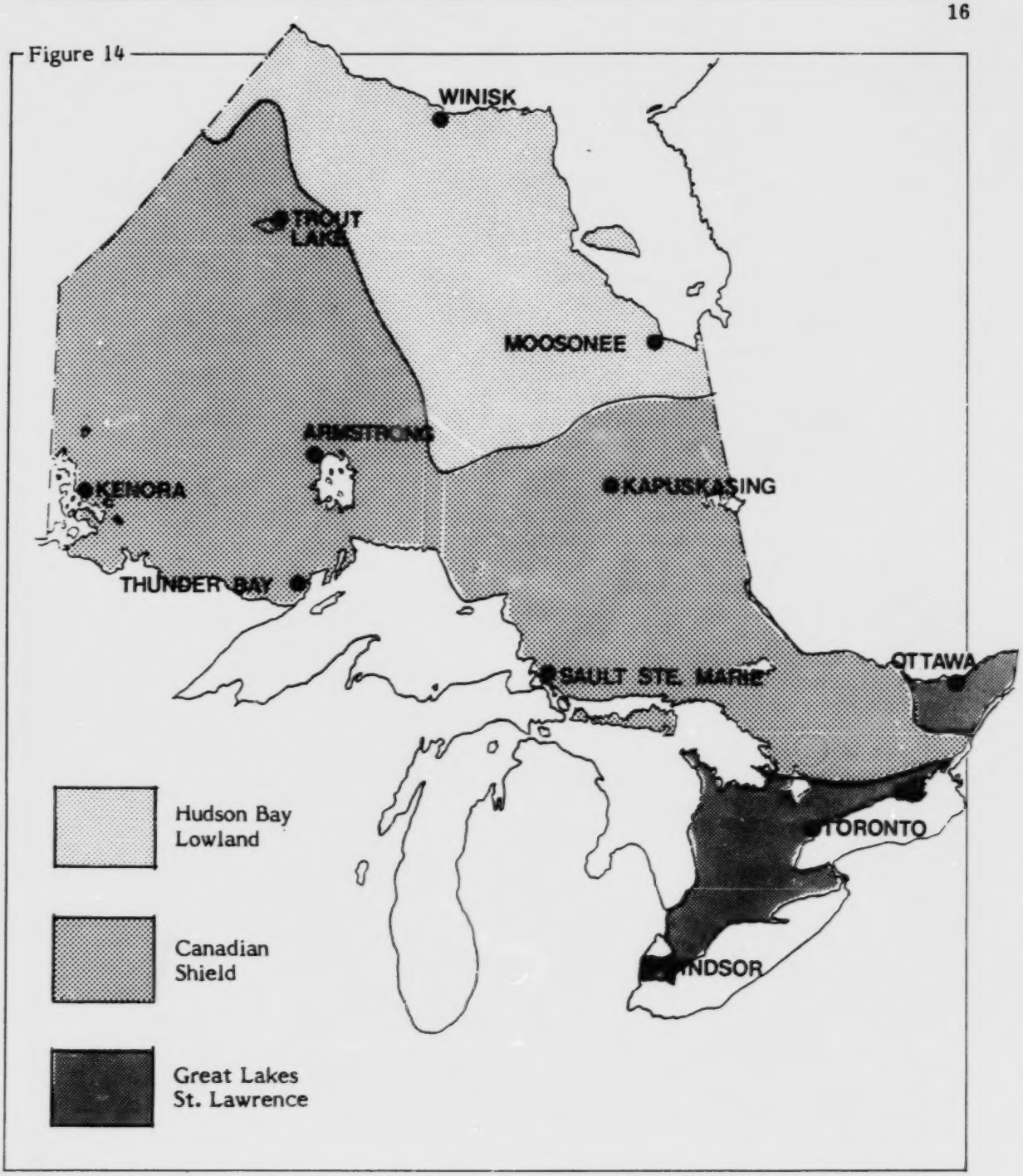
Major Physiographical Types

(4) Origin, Classification, and Use of Ontario Soils, p. 3

(5) Origin, Classification, and Use of Ontario Soils, pp. 32, 33

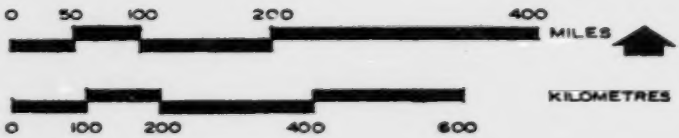
(6) Origin, Classification, and Use of Ontario Soils, p. 33

Figure 14



Physiographic Regions

(Source: Forest Regions of Canada, P.159)



Environment factors such as climate and topography determine the unique character of each soil type through their influence on drainage and living organisms (6). As these factors change from place to place within a region, the soil types which develop may be somewhat diverse even though the parent material is uniform.

Soils may be given an interpretive classification according to use capability or a taxonomic one describing physical characteristics and the developmental processes which created them (7). Table 4 is a chart based on a taxonomic classification and Figure 15 is a map showing the major soil zones of Ontario. There is a close interdependence between soil types and vegetative cover (8).

Table 4

BRUISOLIC Weakly leached brownish soils with little differentiation of the profile horizons. Includes "melanic" and "eutric" on calcareous materials in eastern and western Canada respectively, and "sombric" and "dystric" on acidic materials, most commonly in eastern and western (B.C.) Canada respectively.
PODZOLIC Leached soils with an upper bleached mineral horizon (Ae) underlain by a horizon (Bf) in which accumulate oxides of iron and aluminium. Includes "Humo-ferric" and "ferro-humic" (strongly acid, and may have an "iron pan" accumulation in the subsoil) and "humic" (with distinct accumulation of dark organic materials).
LUVISOLIC Leached soils with an upper bleached mineral horizon (Ae) underlain by a horizon (Bt) in which silicate clays accumulate. Includes "gray brown" and "gray", on moderately calcareous materials under tolerant hardwoods and boreal mixedwoods, respectively.
GLEYSOLIC Poorly-drained soils developed in the presence of a high or strongly fluctuating water table, and usually with mottled subsoil. Includes "humic gleysol" (with a dark humus-rich Ah horizon), "gleysol" (with little or no Ah horizon), "eluviated gleysol" (with a mottled, finer-textured (Btg) subsoil) and peaty phases (with a surface accumulation of raw organic matter) of the previous three groups.
REGOSOLIC Poorly-developed or immature soils with little differentiation, occurring on recent floor plain deposits, shifting dunes or very fine textured lacustrin deposits.
ORGANIC Soils (peats and mucks) which have developed from organic deposits and are saturated for most of the year. No attempt has been made to identify organic soils by the three great groups based on relative degree of decomposition: "fibrisol", "mesisol" and "humisol".

Major Soil Types

3.3 Vegetation Types

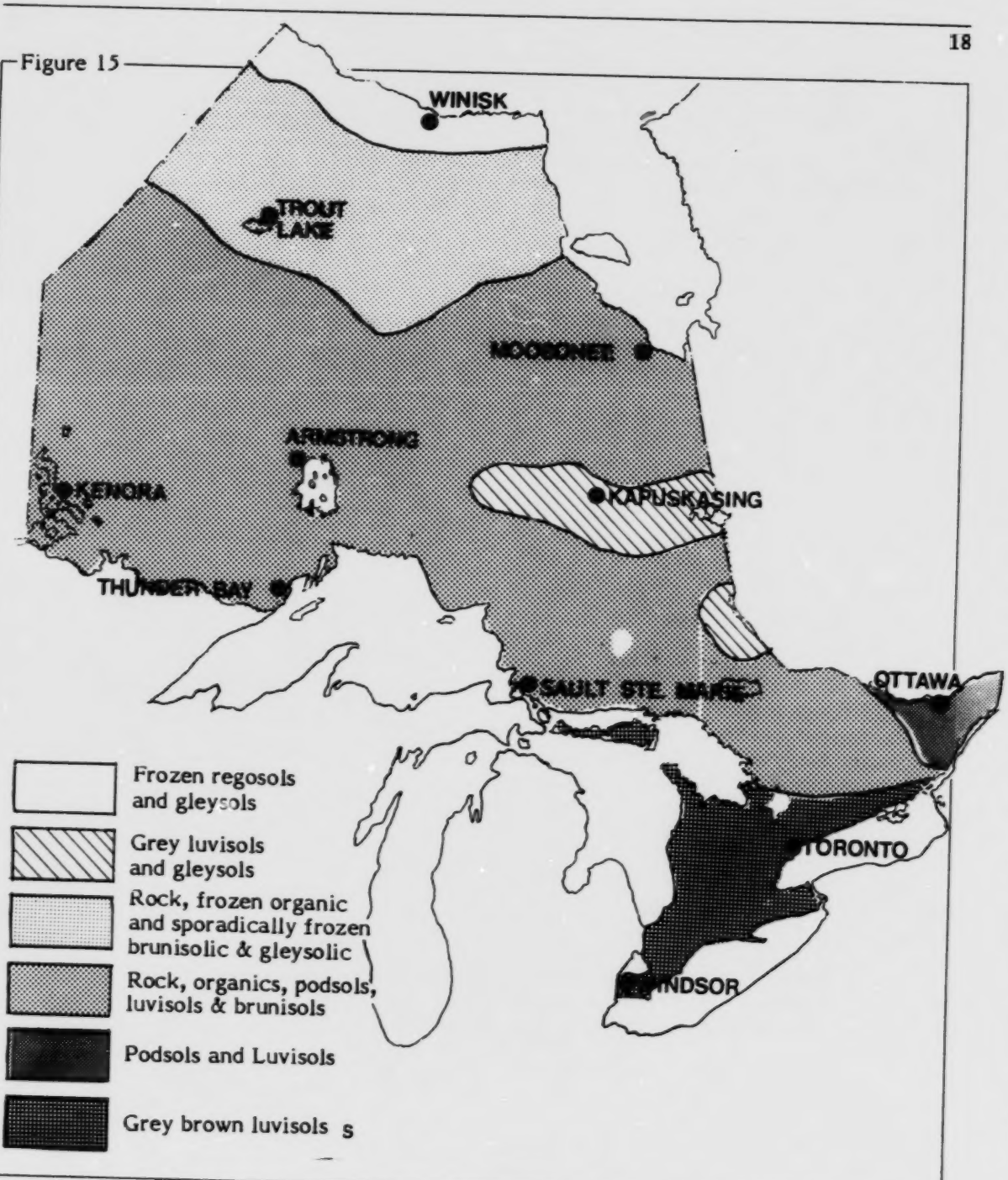
3.3.1 Forest Regions

Although it consists primarily of forests, the natural vegetation of Ontario is diverse and complex. At the most general level, the kinds of natural vegetation vary with latitude. The rich deciduous hardwood forests of the south gradually give way to the coniferous forests in the northern regions. Only along the coasts of Hudson's Bay do the forests begin to disappear to be replaced by tundra vegetation.

The various forest types of Ontario have been classified according to a number of criteria. The forest "regions" refer to relatively large geographical areas which are characterized by the presence of more or less uniform and distinctive climax formations. In particular, regions are identified by the presence of certain plant species, the climax dominants, which serve as "indicator" species. Each region is, in turn, subdivided into sections which encompass distinct variations of the general regional characteristics (9). Figure 16.

(7) Origin, Classification and Use of Ontario Soil, p. 34
(8) Forest Regions of Canada, pp. 160, 164
(9) Forest Regions of Canada, p. 2

Figure 15



Soil Zones and Regions

(Source: Forest Regions of Canada, p. 160)

The vegetation within each region or section is, of course, much more varied than the general description would imply. The diversity of plant communities is the result of many environmental factors including microclimate, soil type, topography, drainage, and man's influence. With respect to the latter, the forest regions refer to either the existing vegetation or to the vegetation which existed prior to man's arrival and which, all things being equal, could once again exist if allowed to develop.

Despite the natural diversity of vegetation, the forest regions identified in the map, Figure 16, do serve to indicate the general patterns characterizing Ontario. For further detail on forest regions and sections, refer to Forest Regions Canada.

3.3.2 Hardiness Zones

The successful importation of plants to a given location is dependent on their hardiness with respect to the local conditions of soil type, rainfall and temperature. While moisture and, to some extent, soil type can be modified the most critical limitation, temperature, particularly minimum temperatures, cannot. There are two ways in which low temperatures can injure plants; damage to plant parts and dehydration. The formation of flower and leaf buds is frequently inhibited by low temperatures in fall or spring and damage may also occur to plants accustomed to short winters if exposed to prologed low temperature. Sudden changes can also cause injury. 'Sun scald' to the southwest sides of trunks and branches is caused by a rapid drop in temperature following a sunny afternoon.

Dehydration is the result of low temperatures and high winds. All plants, especially conifers, continue to transpire during the winter and may be unable to make up the water loss due to frozen ground. This is particularly likely in early spring (10).

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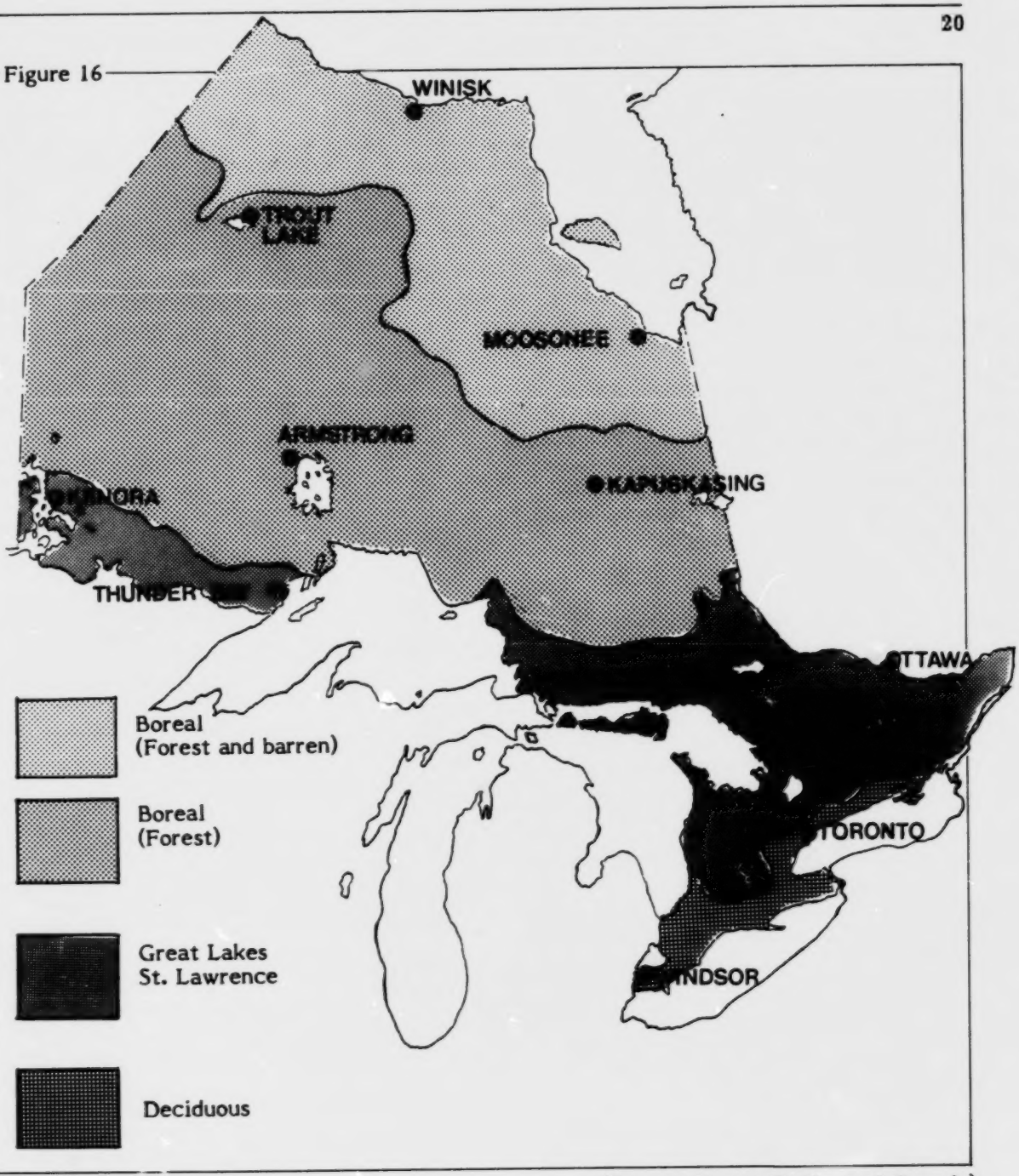
(10) Wyman, pp. 7-12

Figure 16



Forest Regions

(Source: Forest Regions of Canada)

In order to assist in the selection of plants for specific regions, "hardiness zones" have been established which are based primarily on temperature and precipitation. However, due to the number of variables influencing hardiness and to the fact that local micro-climates can greatly influence the survival of plants, hardiness zones are, at best, only very general guides to plant selection. For instance, plants which are sheltered from the wind and exposed to the sun will survive in zones much colder than normally recommended.

The hardiness zones for Ontario are shown in Figure 17, while Table 5 shows the coldest zone in which some typical plants will normally survive and grow. This zone system depends on six criteria:

- mean minimum temperature of coldest month
- mean maximum temperature of warmest month
- length of frost-free period
- amount of rainfall from June to November
- depth of snow cover
- wind velocity

and was prepared by Agriculture Canada (11).

Zone	Deciduous Trees	Coniferous Trees	Deciduous Shrubs	Coniferous Shrubs
1.	Trembling Aspen	White Spruce Black Spruce Jack Pine	Saskatoon Berry Hedge Cotoneaster Buffaloberry	Mugho Pine
2.	Silver Maple Green Ash White Birch	Norway Spruce Colorado Spruce Tamarack	Tatarian Dogwood Rugosa Rose Siberian Peashrub	Common Juniper
3.	Red Oak Linden Mountain Ash	White Pine Scotch Pine Eastern White Cedar	Winged Euonymus Staghorn Sumac Spiraea	American Arborvitae
4.	American Beech Honey Locust Golden Willow	Eastern Hemlock Austrian Pine	Hydranga Mockorange European Elder	Japanese Yew
5.	Norway Maple Catalpa Saucer Magnolia		Early Forsythia Witch Hazel Privet	Chinese Juniper
6.	London Plane Tree of Heaven Sycamore		Japanese Maple Slender Deutzia Japanese Angelicatree	Oriental Arborvitae
7.	Tulip Tree Sweetgum		English Box American Holly	English Yew

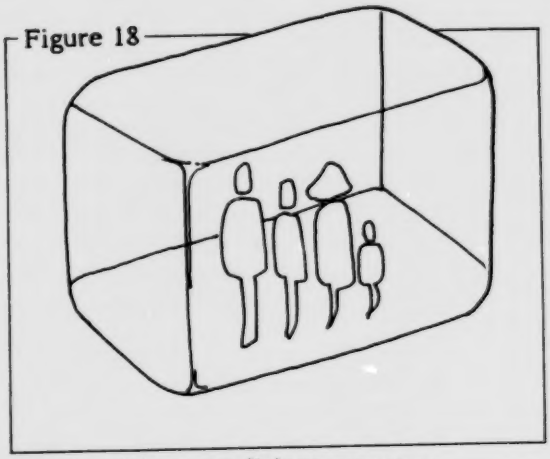
Hardiness Zones and Representative Species

(11) Ornamental Shrubs for Canada

4.1 Introduction

Landscape planning to achieve human comfort with energy efficiency requires the manipulation of the effects of solar radiation, wind, air temperature and humidity. All of these are modified initially by regional geographic features and subsequntly by man's intervention. As the space over which man desires to exert an influence increases, so do the problems and the magnitude of the forces with which he must deal. Thus the modification of climate is best accomplished at the scale of the micro-climate, Figure 18, although as man's capability and experience increase, the dividing line between micro- and meso- moves steadily toward larger spaces.

Figure 18



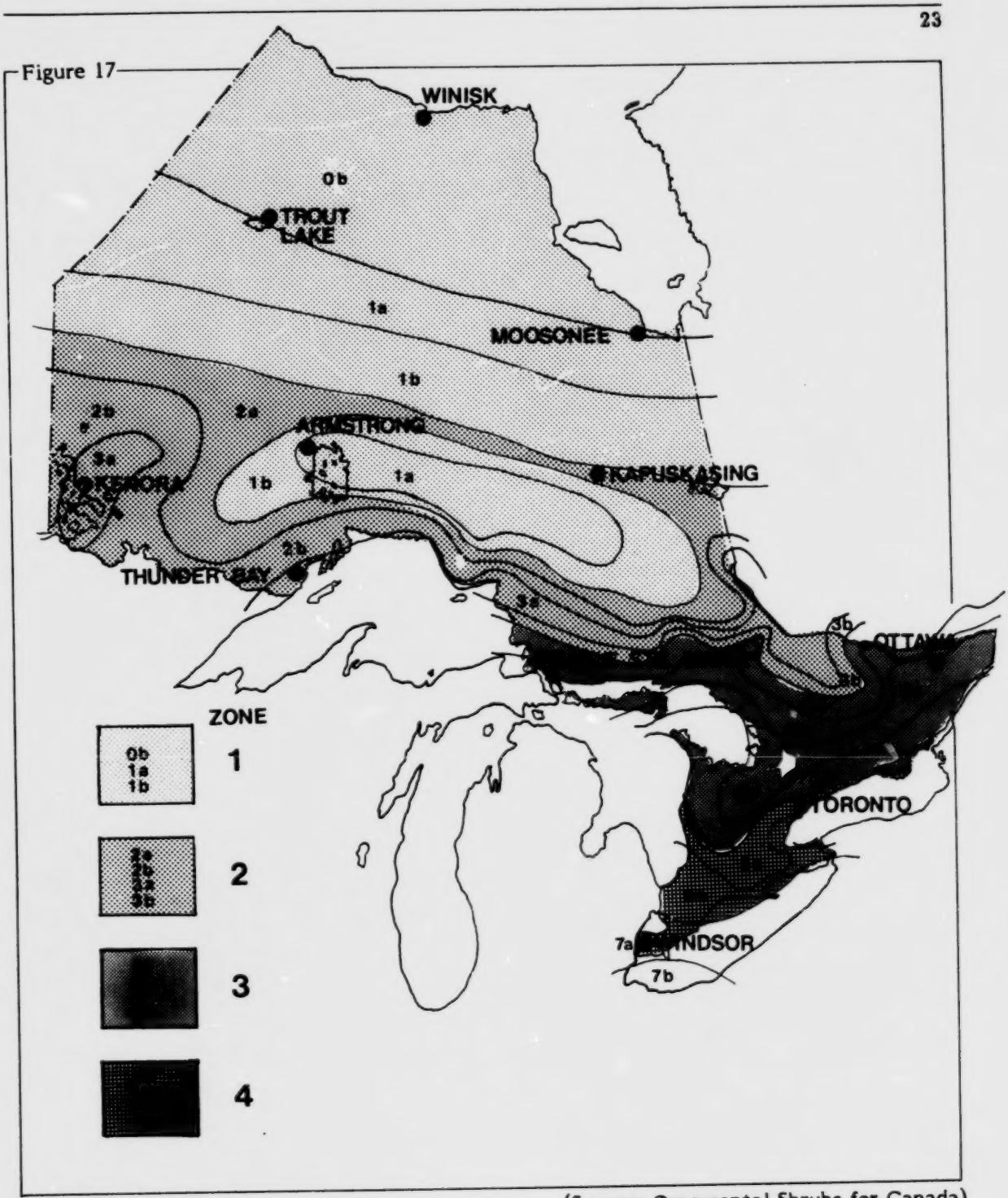
Local ambient conditions are ones Microclimate

Quite aside from the fact that regional climatic control is still beyond man's economic, if not technical capabilities, control at the microclimatic level is a fundamentally better approach. The methods and techniques involved in manipulating microclimate are at the scale on which most environmental design is conducted. Secondly, precision and sensitivity to individual need is possible at the micro level and would not be on a regional basis.

Temperature is the aspect of microclimate which receives, and deserves, most attention but precipitation is another important element. While precipitation control is not the responsibility of the landscape architect, the disposition of stormwater is. Its handling may influence energy consumption both for the owner/inhabitant and for the community at large. Similarly, environments not designed to accommodate snow accumulation can also result in unnecessarily high energy costs.

Althcugh the factors which determine temperature, precipitation and other elements of a microclimate are interrelated it is helpful to examine each one individually. In the following sections a brief discussion on human comfort (and thus energy consumption) precedes a presentation of landscape planning as a means of control.

Figure 17



Plant Hardiness Zones

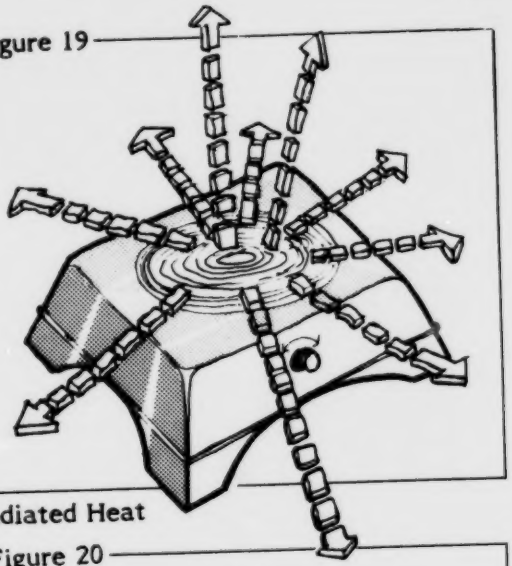
(Source: Ornamental Shrubs for Canada)

4.2 Climate and Human Comfort

In order to understand the relationship among climate, human comfort and energy consumption it will be helpful to review the basic principles of heat transfer, radiation, conduction and convection, and also the concept of latent heat.

Radiation and its converse, absorption, is the transfer of heat from a warm body to a cooler one by the exchange of electromagnetic energy. When a body is very hot, like the sun, much of the energy is in the form of white light, cooler surfaces like the element of a stove, Figure 19, radiate longer red, but still visible rays, still cooler surfaces emit energy in the infra-red range.

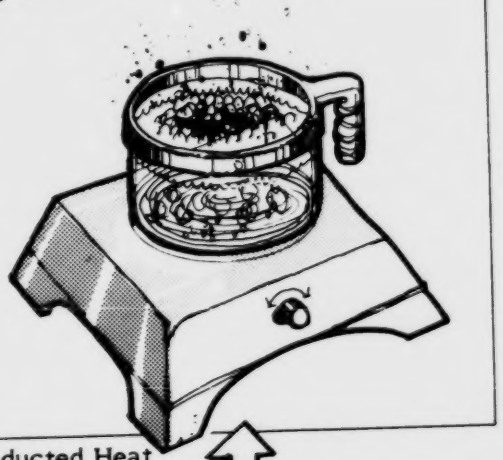
Figure 19



Radiated Heat

Absorption capability - is related to a surface property known as albedo. Light coloured and shiny materials like snow or polished metal have high albedo and reflect most of the received energy, absorbing only a small portion. Bare earth, asphalt and similar rough textured, dark coloured materials have low albedos and are good absorbers and poor reflectors, such surfaces are, however, very effective radiators of energy.

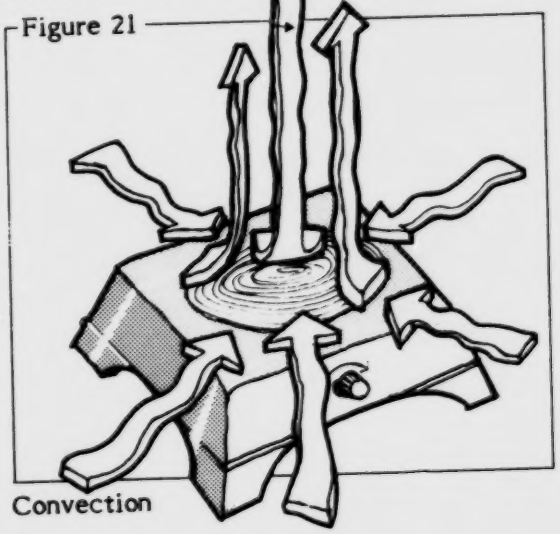
Figure 20



Conducted Heat

Conduction - is the movement of heat through a material or from one material in direct contact with another (Figure 20). Thermal conductivity is a property of the substance. In general, metals are better conductors than non-metal and more dense materials better than those of lower density. Part of the dependence of conductivity on density is because less dense materials frequently contain entrapped air which is itself a poor conductor.

Figure 21



Convection

Convection - is the movement of air (or other fluids) resulting from a change in density which accompanies a change in temperature. The air film close to a surface gains heat by conduction and as its density falls it is replaced by denser (and cooler) air which in turn is warmed and displaced. The end result is the transport of heat away from the warm surface, as shown in Figure 21.

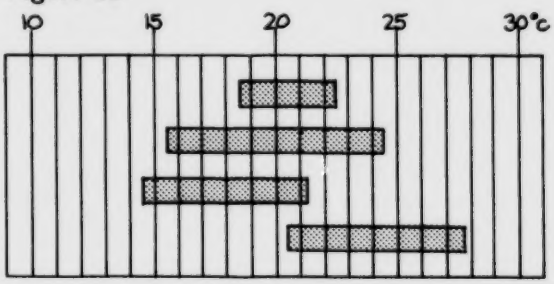
Latent heat - is the term applied to heat energy which a substance can give up in changing its state from a vapour to a liquid or from a liquid to a solid without a change in temperature. In the reversal of the process, latent heat causes the opposite change, again without alteration of temperature. The amount of heat is quite considerable, 80 per cent of the energy required to warm a quantity of water from the freezing to the boiling point is released when the same quantity changes from liquid water to ice. Even though this takes place without change in temperature, the release of heat as sprayed water freezes may prevent fruit or other sensitive crops from freezing.

In terms of human comfort, the most important effect of climate is its impact on perceived temperature. The human body has a precise temperature regulating mechanism which maintains an equilibrium between heat losses and gain. While this equilibrium is maintained, an individual will feel too hot or too cold depending on whether the body is called upon to dispose of excess heat or to reduce its rate of loss.

The precise comfort range is difficult to define for people in general because of individual preferences due to many factors. These include metabolic rates, age, sex, cultural background, experience and psychological and emotional state. Some typical comfort zones are shown in Figure 22.

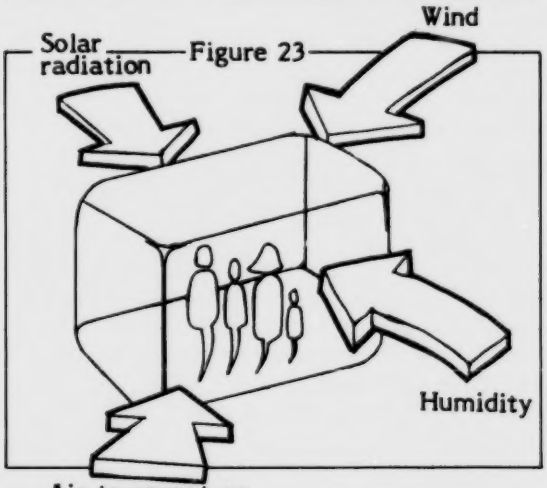
The difficulty of determining precise comfort levels is compounded by the relationship between the effects of the four principal climatic factors, sun, wind, air temperature and humidity as shown in Figure 23. The sun provides radiant heat which warms the surfaces which it strikes. Wind affects rate of heat loss and wind and humidity together determine loss due to evaporative cooling. Air temperature affects loss due to conduction and convection. In addition, the effect of one factor can offset that of another. A person may feel comfortable at low temperature if the sun is shining or at a high one with a pleasant breeze. The effects of changes in two variables is shown schematically in Figure 24, A-C.

Figure 22



Human Comfort Zones
(Adapted from Robinette, 1977)

Figure 23



Microclimatic factors

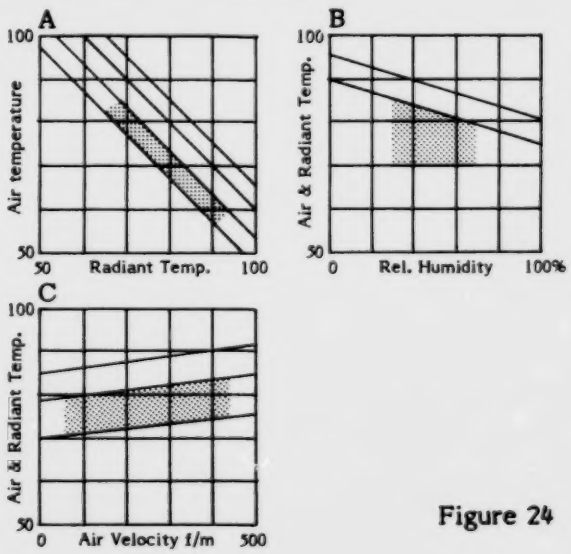


Figure 24

4.3 Sun

4.3.1 Introduction

The virtually inexhaustible energy of the sun reaches the earth as ultraviolet rays, visible light and infra red radiation at a rate some 25,000 times man's total rate of energy usage (1). Although some of this energy is reflected back into space by the atmosphere or the earth's surface as shown in Figures 26 and 27, the amount is so vast that to capture even a small part of it has been the goal of a great deal of research during the past decade. A considerable portion of this research is related to landscape planning in enhancing the beneficial effects of solar radiation.

In Canada much of the research has been directed toward the replacement of fossil fuels with solar radiation for space heating. Solar heating systems are designated as active or passive according to the relationship between the collecting medium and the space to be heated. In an active system a working fluid, usually air or an antifreeze, mixed with water is heated as much as possible in a solar collector and then blown or pumped to the point of use. In a passive system, solar radiation is admitted directly into the structure which is designed to absorb large amounts of energy without an uncomfortably great temperature change whenever sunshine,

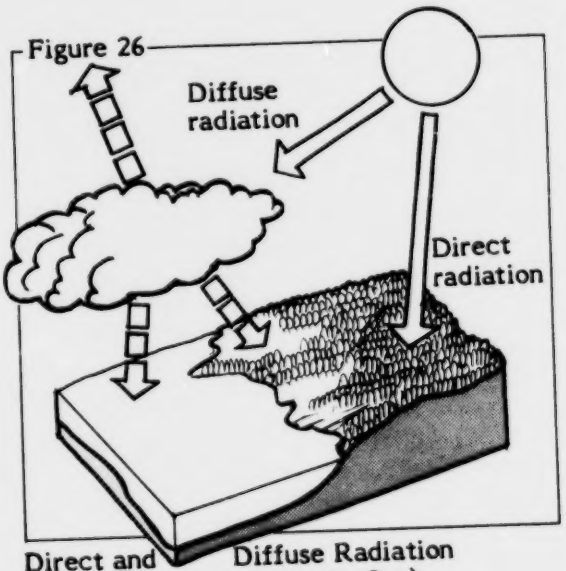


Figure 26
Direct and Diffuse Radiation
(Adapted from Turn on the Sun)

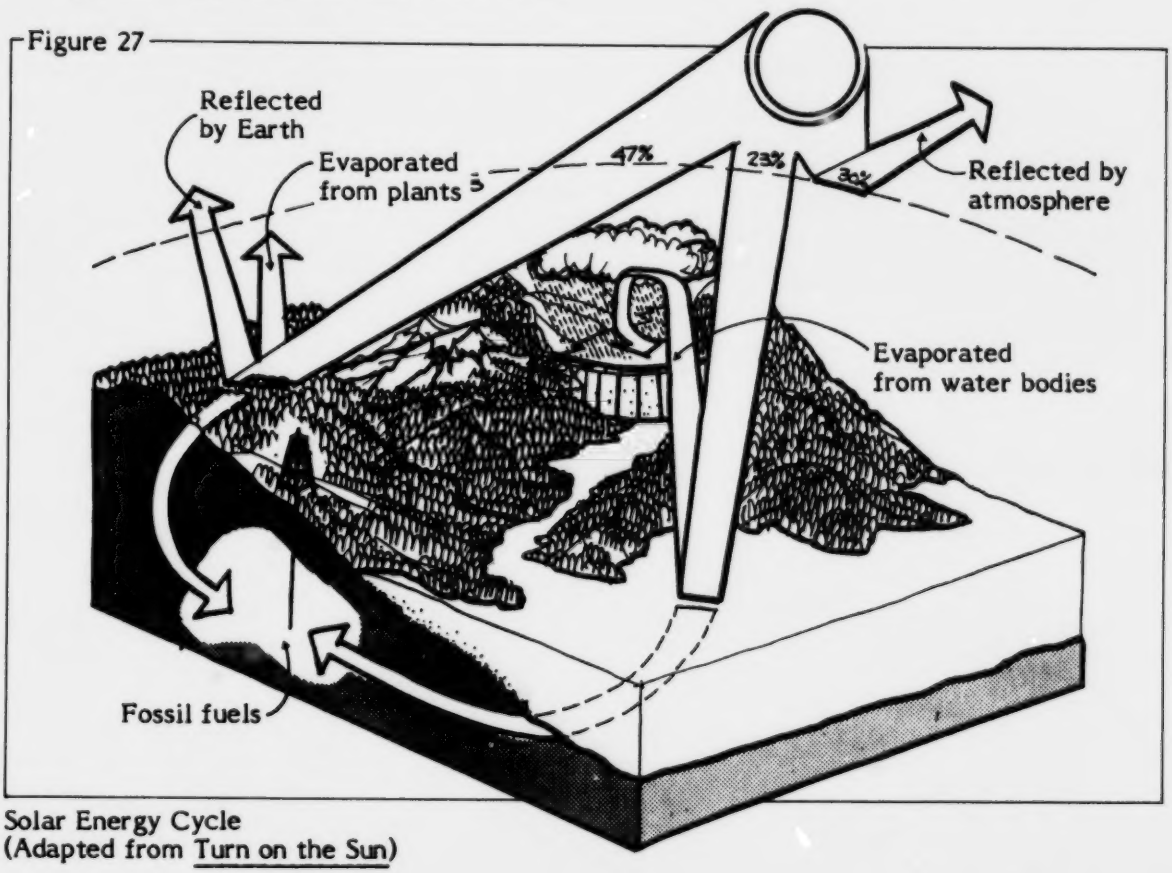
(1) Merill, p. 52

direct or diffuse, is available. The stored heat is gradually distributed to the living space by convection and conduction. The availability of sunshine is affected by building placement and orientation with respect to site topography and other structures and by use of vegetation, the responsibility of energy efficient landscape planning.

Similarly, solar radiation is an important consideration in the design of comfortable and cost-effective outdoor environments. Although there has been less research on solar heating in outdoor spaces, it is clear that among the benefits of sunlight are early spring and late fall use of such areas.

It is also important to protect buildings and outdoor spaces from too much solar radiation during the summer to avoid or reduce the energy cost of air conditioning. In the following section, landscape planning is discussed as a means of solar radiation control to minimize the energy cost of too much as well as too little.

Figure 27



Solar Energy Cycle
(Adapted from Turn on the Sun)

4.3.2 Solar radiation control as a design objective

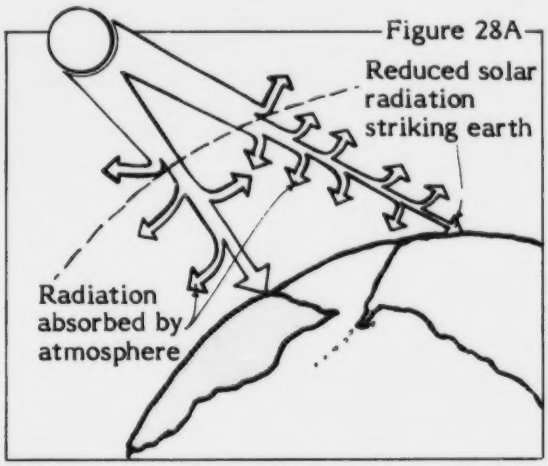
The intensity of solar radiation striking the earth's surface varies with latitude, season and time of day (2) because of their effect on the angle at which the sun's rays pass through the atmosphere. At low angles the radiation is distributed over a larger area (Figure 28B) than if the sun were overhead and in addition the path through the atmosphere is longer, as shown in Figure 28A. The absorption by particulate matter causes the cool, red appearance of the sunrise and sunset when the path is longest.

The location of the sun at any time relative to a point on earth is defined by its altitude or elevation and its azimuth (Figure 28C). Altitude is the vertical angle above the horizon and azimuth is the clockwise angle from due north as shown in Figure 28D. A diagram dividing the location of the sun for any time of day and month of the year can be prepared for a particular point on the earth's surface. Figures 29 and 30 are such sun diagrams for Trout Lake and Kingston.

4.3.3 Maximizing heat gain

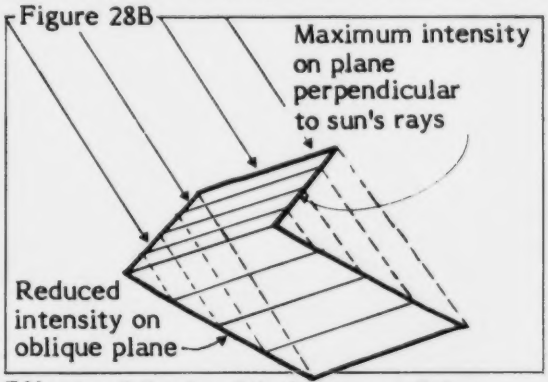
Although a detailed discussion of building design for solar heating will not be attempted, some brief description of concepts is needed. In general, solar heated buildings are designed to collect and store heat from the sun and distribute it throughout the interior spaces.

Figure 28A



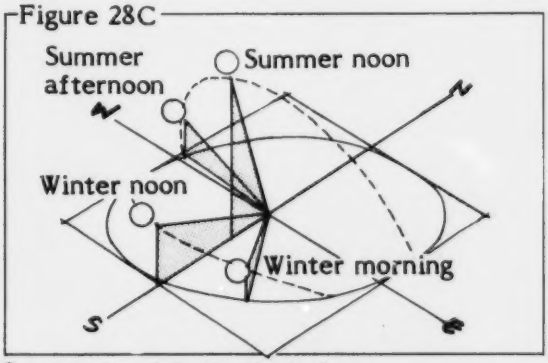
Effects of the Atmosphere on Solar Radiation

Figure 28B



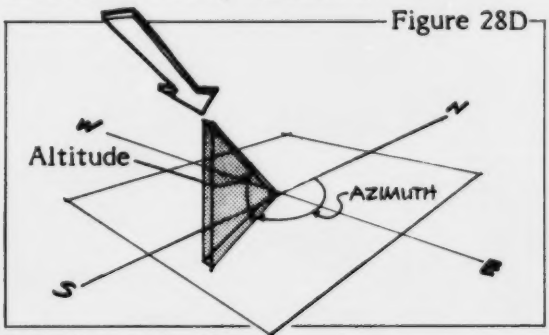
Effects of Angle of Incidence on Solar Radiation

Figure 28C



Seasonal and Daily Variations

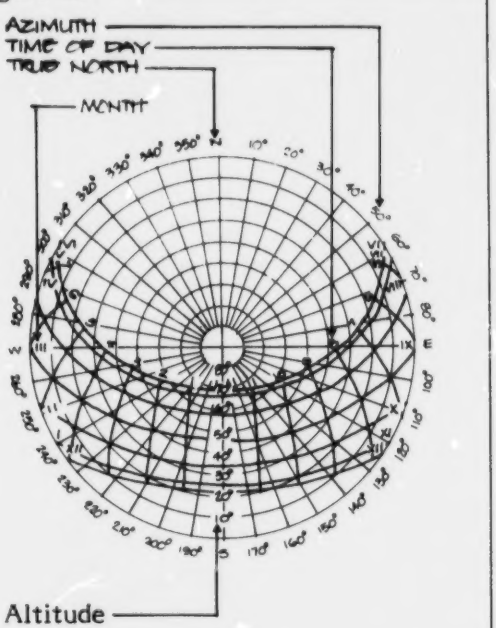
Figure 28D



Location of the Sun

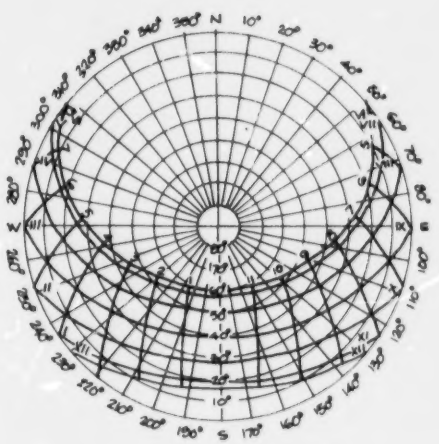
(2) Merill, p. 48

Figure 29



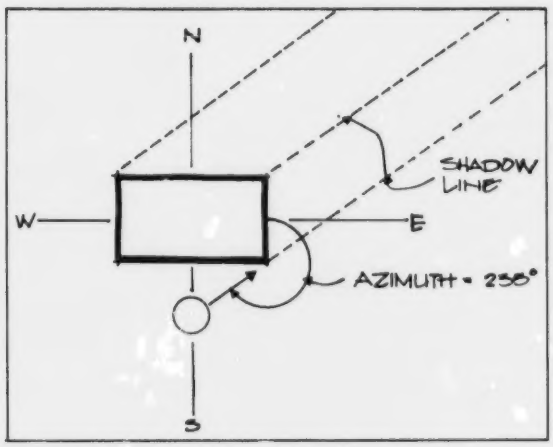
54°N Latitude
(Trout Lake)

Figure 30

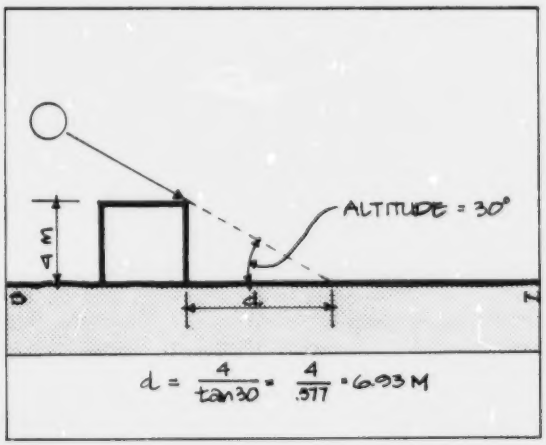


44%N Latitude
(Kingston)

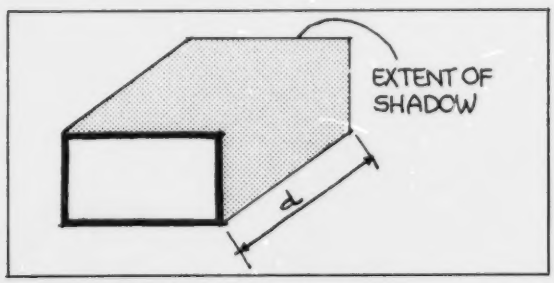
Figure 31 — Plotting shadows by Using Sun Charts



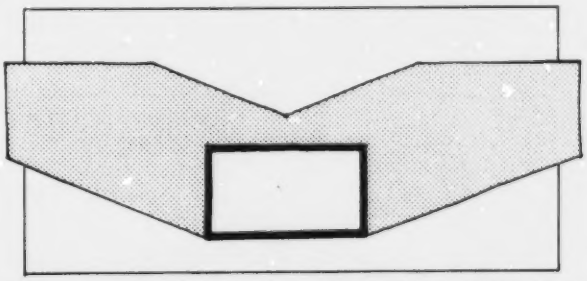
Plan View
Step 1: Plotting of azimuth



Section
Step 2: Calculation of distance



Step 3: Plotting of shadow

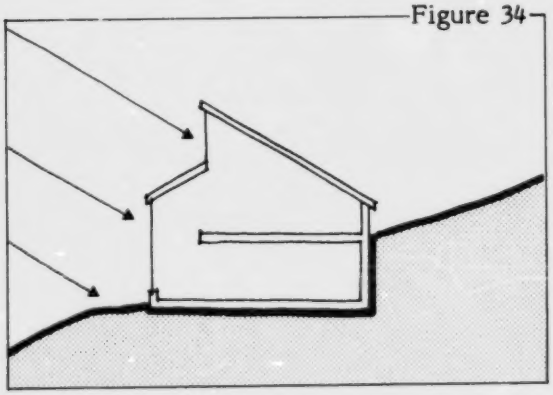


8:oo a.m. and 4:00 p.m. September, Kingston
Plotting of shadow for complete day.

The distinction between active and passive solar systems is illustrated in the contrast between Figures 32 and 33. Whichever system is adopted, its effectiveness is dependent upon sunlight during the time of the year when it is required. Appropriate site selection planning and design are particularly important for the more cost effective passive systems (3) which rely on direct penetration of sunlight into interior spaces.

Site selection criteria include freedom from shading by terrain, vegetation and other buildings. It is generally accepted that south facing slopes which permit large south facades are the most advantageous. They also permit a greater density of construction than north slopes (4). These points are illustrated by Figures 34 and 35A and B.

Figure 34



South-facing slopes

The building itself should ideally be oriented so that the collecting facade faces south or slightly to the east as shown in Figure 36 to obtain rapid morning heating (5). However, it has been found (6) that even with the facade as much as 35° off south that solar collection can still be 95 per cent as efficient as when it faces due south. This tolerance may be of value in reducing vulnerability to wind, another important consideration discussed below.

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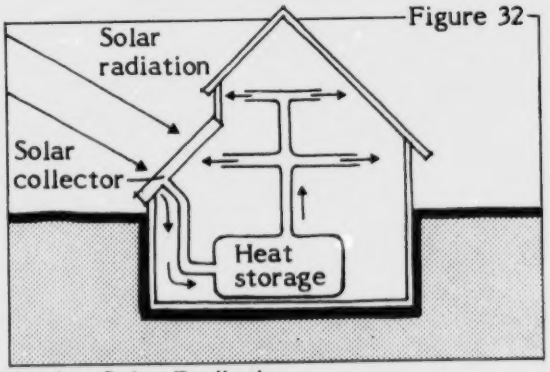
(3) The Conservation of Energy in Housing, p. 99

(4) Site Planning for Solar Access, p. 39

(5) Subdivisions and Sun, p. 39
Costs and Benefits of Environmental Planning Practices, p. 57

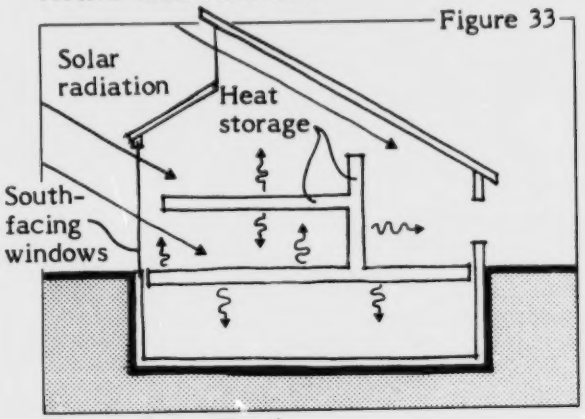
(6) Site Planning for Solar Access, p. 53

Figure 32



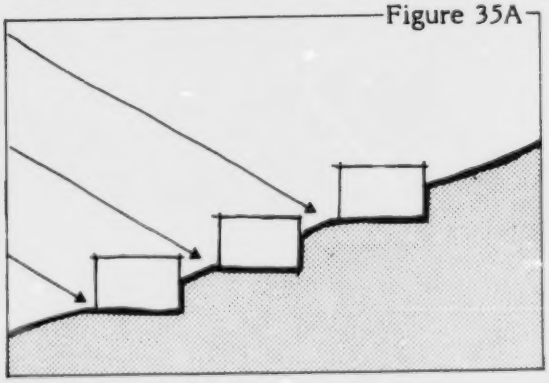
Active Solar Radiation

Figure 33



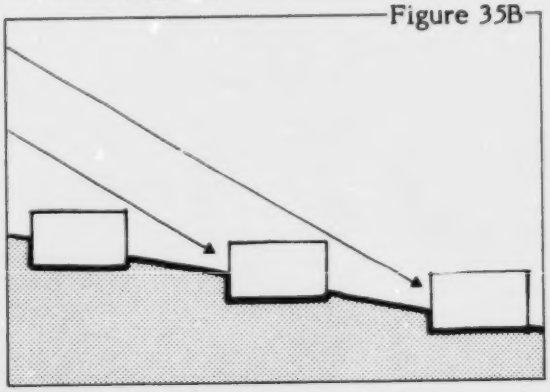
Passive Solar Heating

Figure 35A



South-facing slopes

Figure 35B



North-facing slopes

The basic planning of solar heated buildings and adjacent outdoor spaces should be based on the concept of locating the most actively used spaces where they will benefit most from solar heat gain. Kitchens, dining rooms and living rooms are usually heavily used and should be located on south sides of buildings. Similarly, frequently used outdoor spaces are located on the south sides of buildings (7) (Figure 37).

The appropriate design of outdoor spaces surrounding solar heated buildings can both contribute to the efficiency of the solar heating and can provide extensions of interior spaces which are usable for much of the year. In terms of contributing to the solar heating of interior spaces, it is essential that the site be planned and designed to provide the collectors or building with optimum exposure to the sun. Elements which may produce shade, such as fences, walls, other buildings and vegetation, should be located so that they do not shade collectors or south facades during the times of the year when solar heating is needed (Figure 38). Deciduous trees, which may be necessary to shade these spaces and buildings during the warm periods of the year, should have thin branches and trunks so that they do not substantially reduce the amount of sunlight passing through them. Examples of deciduous trees which allow the maximum penetration of sunlight in winter include Honeylocust, Ginkgo and Mulberry.

The amount of sunlight entering the building can be increased by providing reflective surfaces in the spaces adjacent to the south facades. Light coloured paving materials like concrete will reflect much of the light striking them. Since it is an excellent reflector, snow can be allowed to accumulate on lawns or other low use areas adjacent to south facing facades (8) (Figure 39).

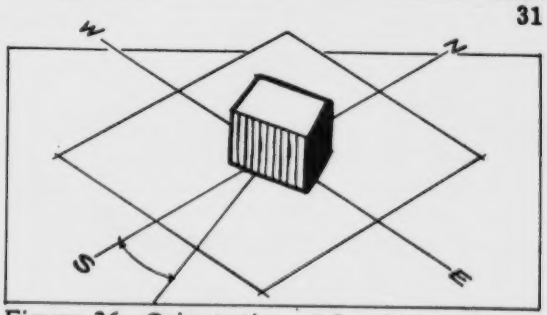
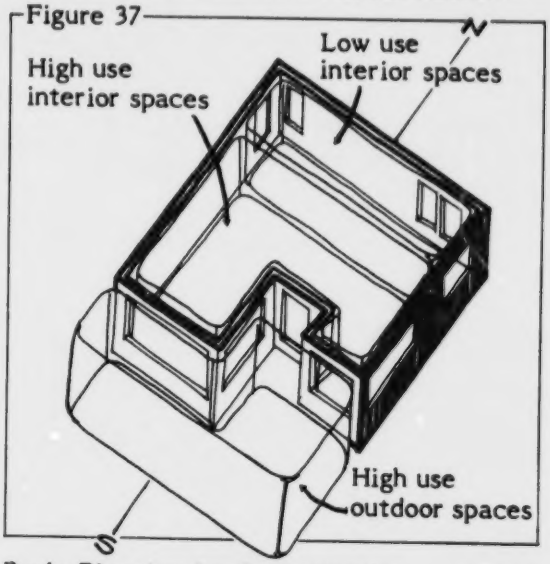


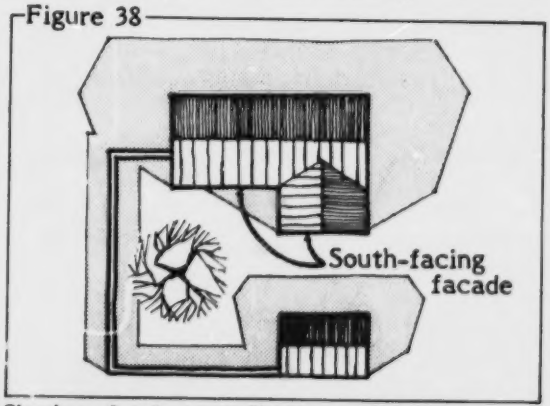
Figure 36 Orientation of South Facade

Figure 37



Basic Planning for Solar Heating

Figure 38



Shadow Analysis to Ensure Solar Access

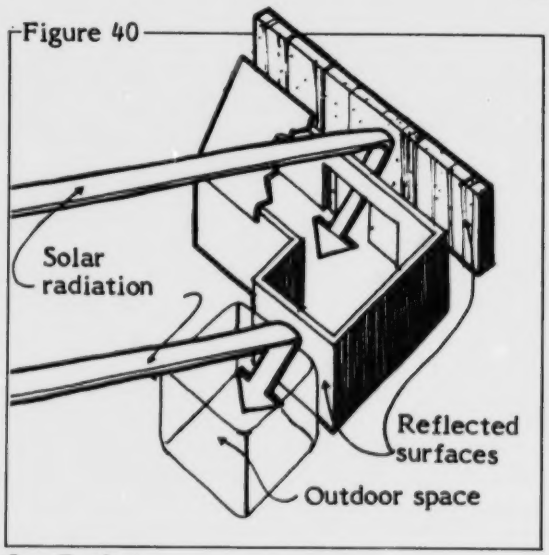
Figure 39

Reflection of Sunlight from
Light Coloured Surfaces

(7) Builder's Guide, p. 14
(8) The Conservation of Energy in Housing, p. 27

The location of outdoor spaces on the south sides of buildings is based on the concept of the "sun pocket" (9) (Figure 40). The warming effect of the sun can be increased by concentrating the sun's rays in a small area. This technique is frequently used in the design of solar collectors, Figure 41, but can also successfully be used to develop outdoor spaces which are comfortable for much of the year. Light coloured elements such as building facades, walls, or fences can be used to reflect heat into outdoor spaces as well as to reflect light into north facing windows (10). Materials which reflect sunlight include smooth-finished concrete, aluminum, or white paint.

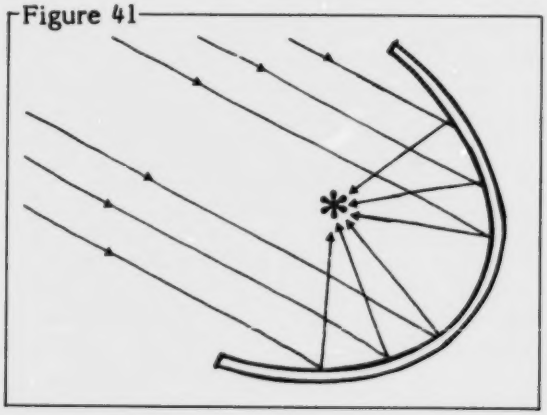
Figure 40



Sun Pockets

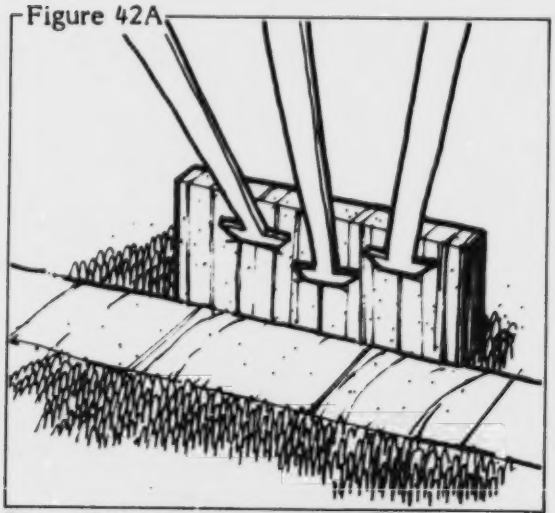
Alternately, dark coloured and heavy walls or fences will absorb and store much of the sunlight striking them and will continue to radiate heat well into the evening. Heat absorbing and storing materials include dark painted concrete, dark brick, or heavy timber. Figures 42A and B.

Figure 41



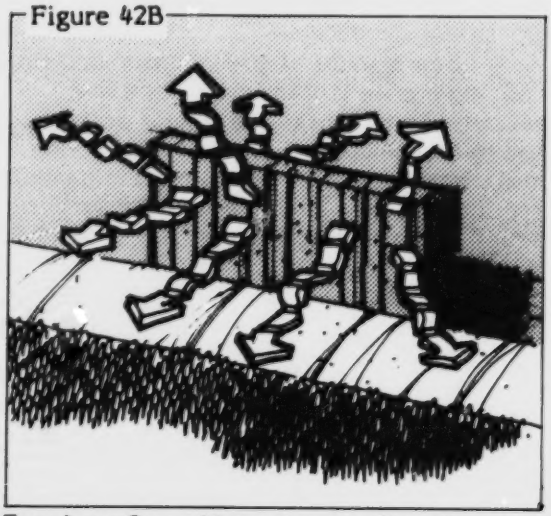
Since light coloured materials reflect heat and dark materials absorb heat, the selection of materials for vertical surfaces adjacent to outdoor spaces should be based on analysis of the activities occurring in the space. If spaces are used primarily during the day (for example, playgrounds) then

Figure 42A



Day: Wall absorbs solar radiation

Figure 42B



Evening: Stored heat is re-radiated

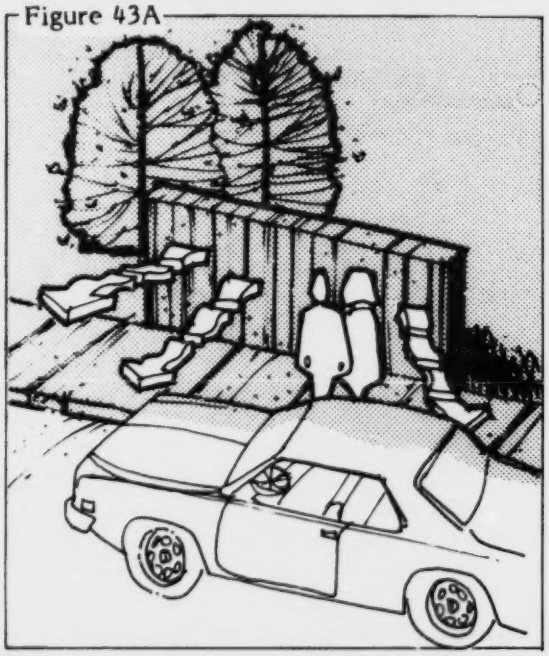
(9) Robinette, 1977, p. 106
(10) Robinette, 1977, p. 117

light coloured materials may be most appropriate. Conversely, if spaces are used throughout the evening (for example, sidewalks) then dark materials which store heat will provide warmth after the sun has disappeared (11). See Figures 43A and B.

4.3.4 Minimizing summer heat gain

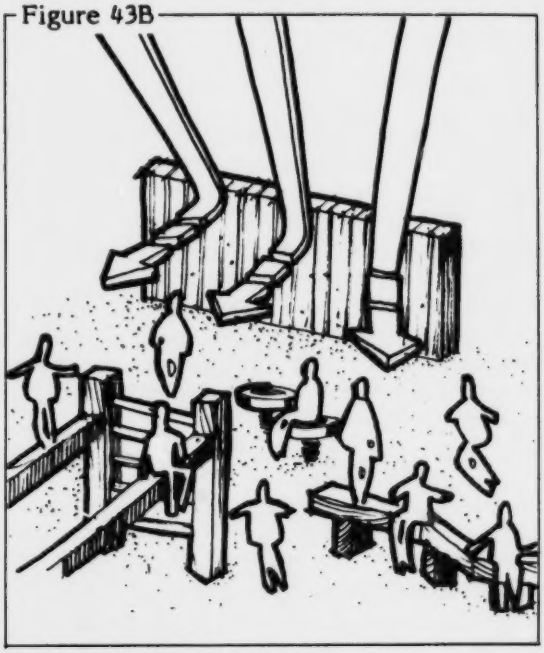
In many parts of Ontario inadequate protection from the summer sun can lead to under-utilized outdoor spaces and the consumption of fossil fuels to cool buildings. Excessive heat gain from solar radiation is a particular problem for solar heated buildings which invariably have large areas of glazing exposed to the sun.

Figure 43A



Dark surfaces absorb and radiate heat

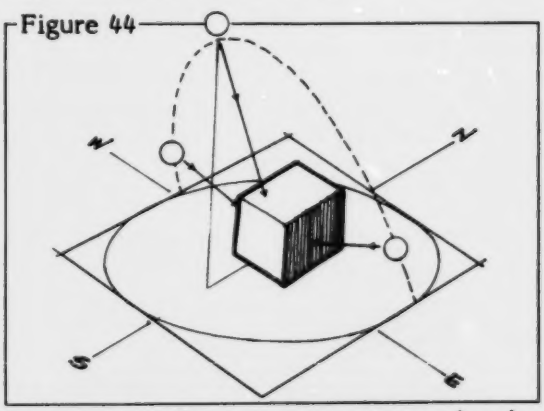
Figure 43B



Light surfaces reflect heat

The reduction of summer heat gain is an important consideration in building design and can influence the building's form and orientation. During the summer, the sun is very high in the sky at noon and rises and sets north of the east-west axis. For this reason, the maximum heat gain in building occurs through the roof and the east and west facades, as shown in Figure 44. In contrast, the south facing facade receives little or no direct solar radiation. Therefore, to minimize solar heat gain, the

Figure 44



Summer: maximum exposure on roof and east/west facades

(11) Robinette, 1977, p. 122

east and west facades can be reduced in size by orientating the long dimension of the building along the east-west axis (12). Extending this principle to groups of buildings, the exposure of east and west facades can be reduced by joining adjacent buildings. These points are illustrated by Figures 45A, B, and C.

Figure 45A

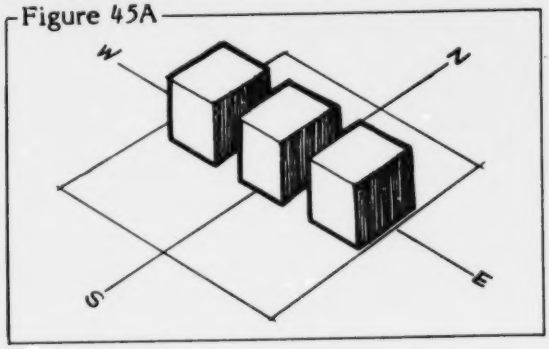
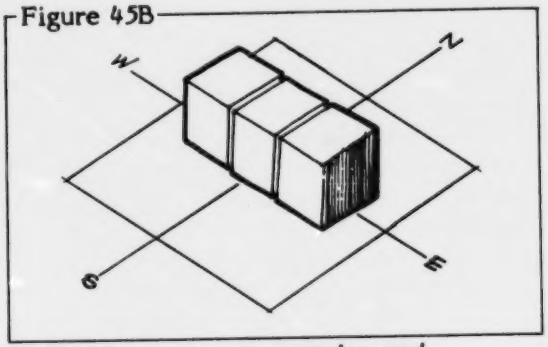
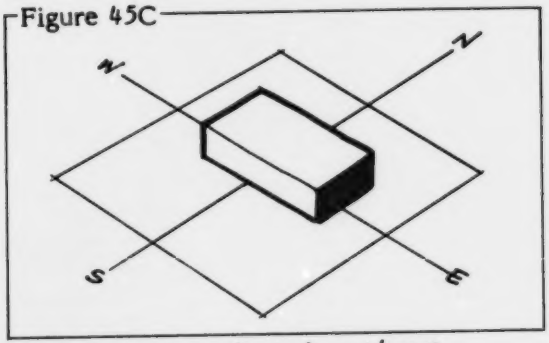


Figure 45B



Reduced exposure to morning and afternoon sun

Figure 45C

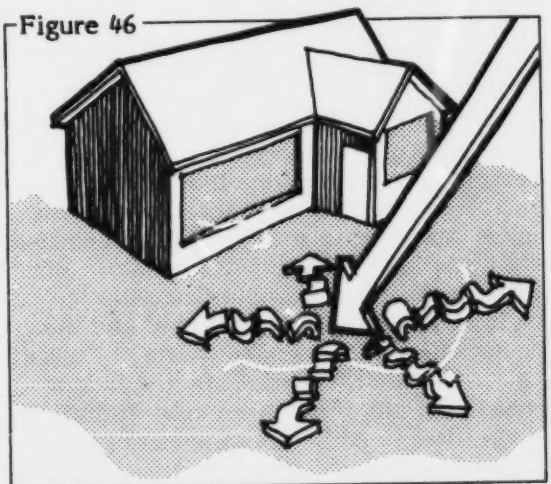


Long dimension oriented east/west
Maximum exposure to winter sun
Minimum exposure to summer sun

The amount of solar radiation entering the building in summer can also be reduced by controlling undesirable reflection from adjacent surfaces. Heat gain from paving, fences and walls can be reduced by using materials with low reflectivity and high conductivity. For example, vegetative ground covers and dark fences reflect little light and can be used in areas where reflection might be a problem (13), as shown in Figure 46.

While decreasing the exposed surfaces of buildings and controlling the reflection of sunlight are important, the most versatile and effective method of reducing solar heat gain involves using vegetation and architectural elements to shade buildings and outdoor use areas. It has been demonstrated that the air conditioning needs for a mobile home in a stand of deciduous trees would be 75 per cent less than for a similar structure in the open. Although this study was conducted in Florida, it shows the potential effectiveness of shade trees in reducing the energy consumed for cooling (14).

Figure 46



Grass and other groundcovers reduce reflection and glare

(12) Robinette, 1977, p. 75
Site Planning for Solar Access, p. 52

(13) Builder's Guide, p. 16
The Conservation of Energy in Housing, p. 26
Robinette, 1977, p. 75

(14) De Walle, 1980

Because of its size, form and growth characteristics, the most useful plant material for shade production is the deciduous tree. In addition to having high, dense canopies with open understories, deciduous trees lose their leaves in the fall allowing the sun to reach the ground during the cold months. The effect is contracted in Figures 47A and B. Attempting to determine the effectiveness of plants for shade, studies have shown that deciduous forests can absorb and reflect up to 90 per cent of the incoming solar radiation (15).

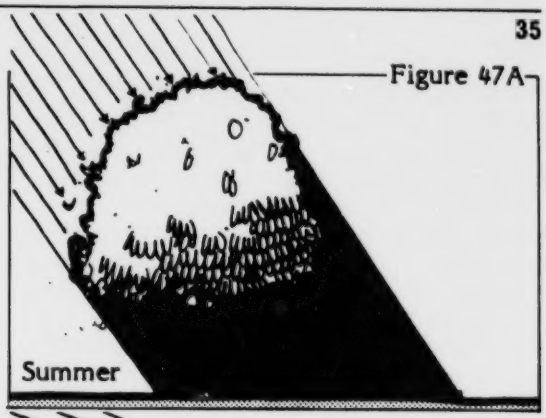


Figure 47A

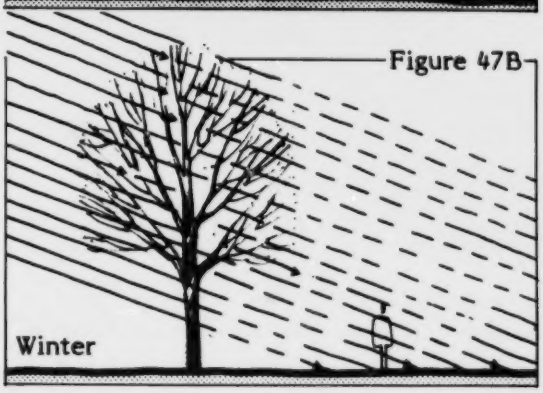


Figure 47B

The value of different species of deciduous trees for shade production varies according to the form of the tree, the rate of growth, the density of the canopy, and how long the leaves are retained. All of these factors should be considered when selecting plants and should be analyzed in terms of the particular requirements of the building or space to be protected.

The shape of the shadow cast by a tree is determined by the angle of the sun and the form of the plant. Naturally, the shadow cast by a tree tends to become elongated and to cover a greater area during the early morning and late afternoon. The forms of deciduous trees vary from tall and columnar to broad and spreading. In the accompanying diagrams of Figure 48, the forms and shadow patterns of typical deciduous trees are illustrated.

48A

Noon

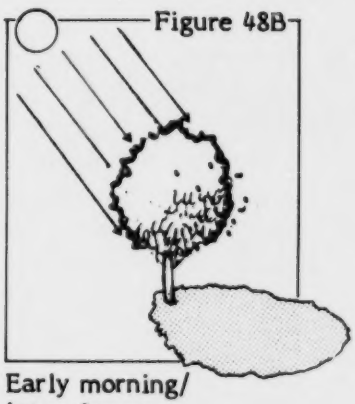
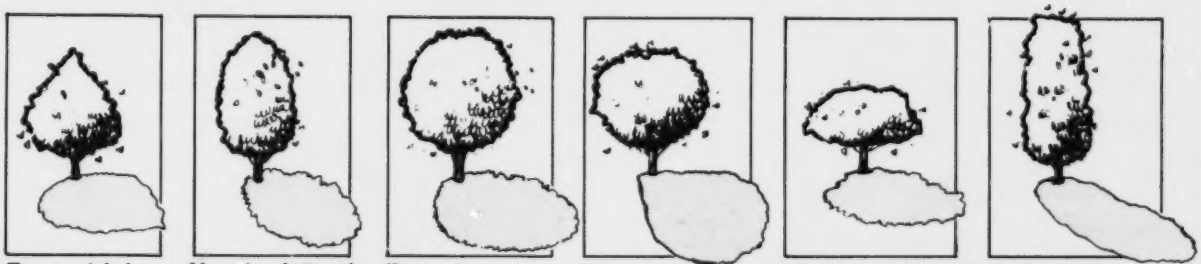


Figure 48B

Early morning/
late afternoon

The rate of growth is also an important factor due to the time required for a plant to reach the size necessary to provide adequate shade. While fast-growing trees will provide shade quickly, it should be

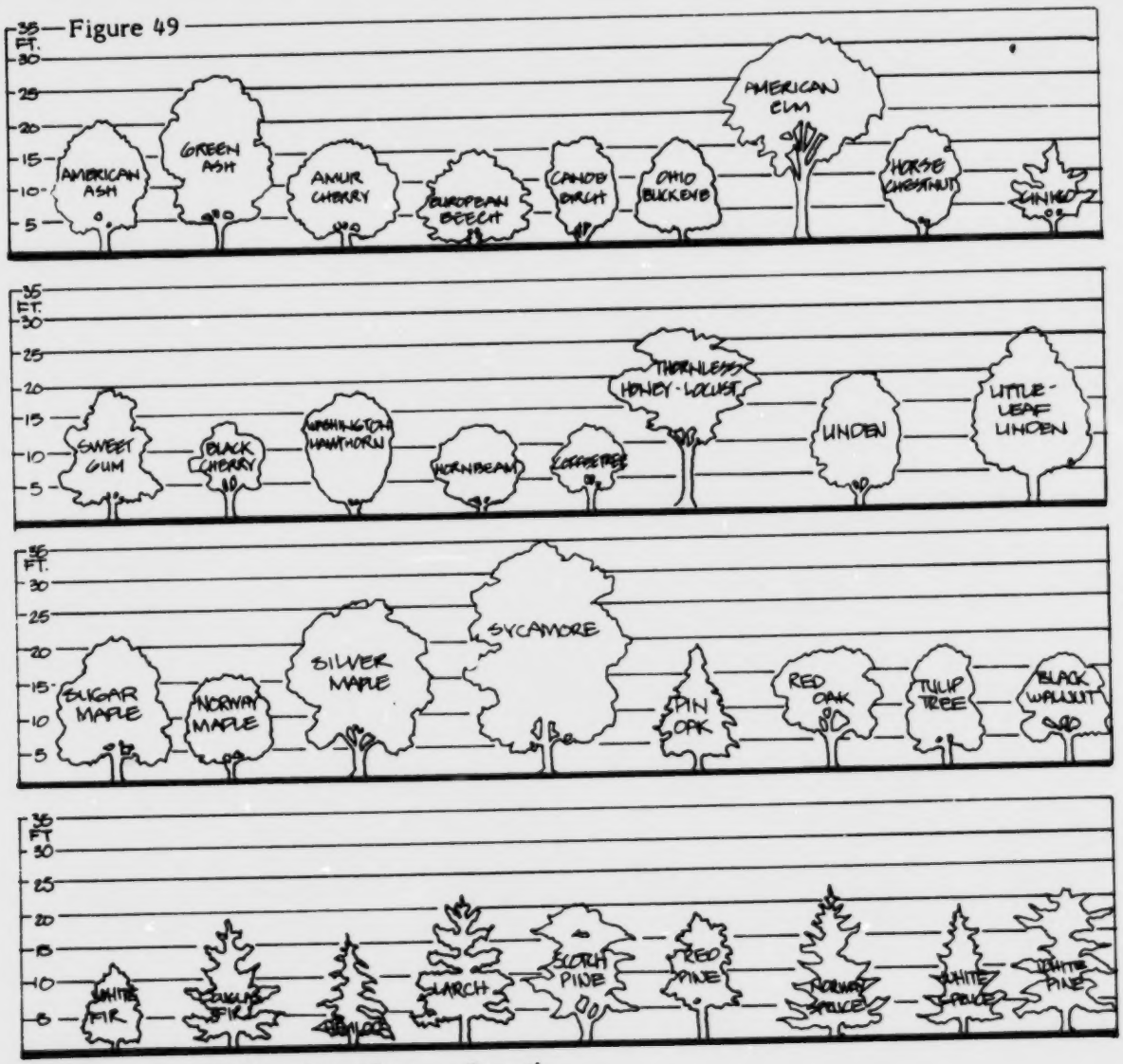


Pyramidal (Linden) | Vertical Oval (Balsam Popular) | Round (Norway Maple) | Vase (Elm) | Horizontal Oval (Crab-Apple) | Columnar (Lombardy Popular)

Shade Patterns of Various Trees

(15) Reifsnyder and Lull, 1965, p. 63

remembered that these trees, including the Poplars and Willows, often have relatively short life spans. A planting strategy which is useful in many circumstances involves the use of a combination of fast- and slow-growing trees; the fast-growing trees provide short-term shade while the slow-growing but more lasting trees, like Maples and Oaks, mature. The accompanying diagram (Figure 49), was prepared at the Morton Arboretum in Illinois and illustrates the relative growth rates and forms of selected trees.



Tree Form and Height after 10 years Growth
(Source: Trees for American Cities, p. 101-102)

The density of the tree's canopy determines how much light will penetrate through the leaves and branches. Some trees like Honeylocust or Trembling Aspen have very thin textured crowns which provide light and usually mottled shade. Other tress, like Norway Maple and Linden, have very dense canopies and block all the solar radiation striking them.

The dates when the leaves first appear on the tree in the spring and when they fall in the autumn is quite variable and may influence the effectiveness of the tree. This is particularily true in the fall when solar radiation may be blocked by the leaves at a time when warming is desired. As a general rule, trees which leaf out early in the spring and drop their leaves late in the fall. Trees which leaf out late and drop their leaves early include Honeylocust and many of the Ashes. It should also be mentioned that some trees, in particular Oaks, retain some of their dead leaves through the winter; these trees tend to inhibit the penetration of sunlight during the time of year when warming is most required.

The selection of specific trees and their arrangement on the site depends upon a great many factors bearing upon the type of building or outdoor space to be protected, the amount and location of the desired shade, and the time of day and year when it is most necessary. In terms of energy efficiency in small buildings, deciduous trees should be selected and arranged so that they provide shade during the hottest periods of the summer while permitting maximum penetration of sunlight in winter. Olgyay, in his book Design with Climate, illustrated one possible approach to this problem. Deciduous trees are located to the southeast and southwest of the building in order to provide shade from the morning and afternoon sun. Because the noon sun is nearly directly overhead, windows are best shaded by overhangs and other architectural features; at noon, the shade from deciduous trees falls directly beneath and provides little protection for adjacent buildings (16). The use of trees in this way also provides maximum insolation on the south facade of the building during winter.

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(16) Olgyay, p. 76

Trees intended to shade buildings should be large with high arching crowns and might include Silver Maple or Siberian Elm. Trees intended to shade lawns or other outdoor spaces, on the other hand, often have broad and spreading crowns which provide large pools of shade; examples of these would include American Beech or Crabapples (17). The difference is illustrated by the sketches of Figure 50.

Figure 50A

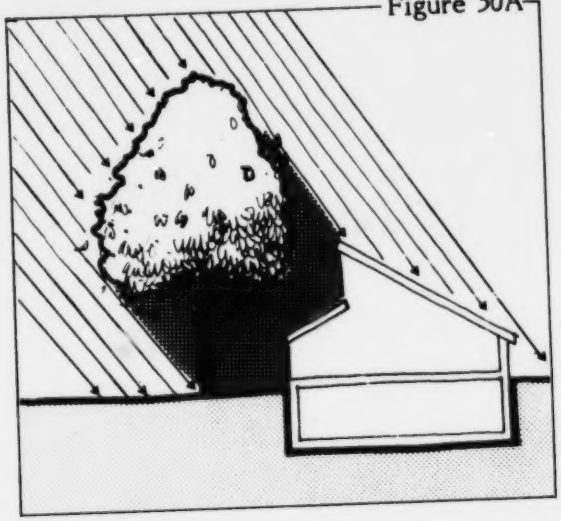
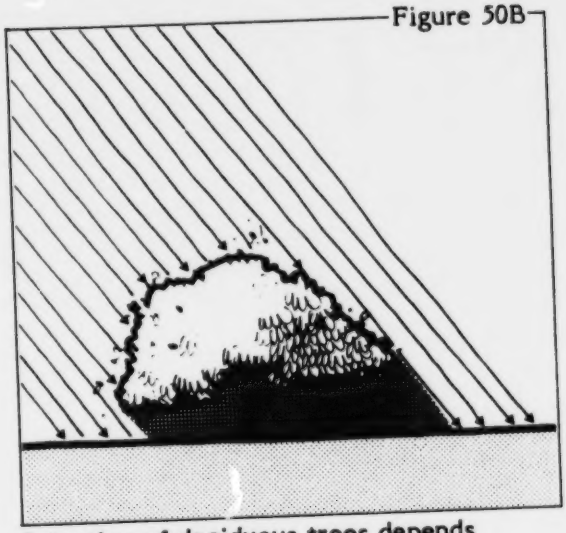


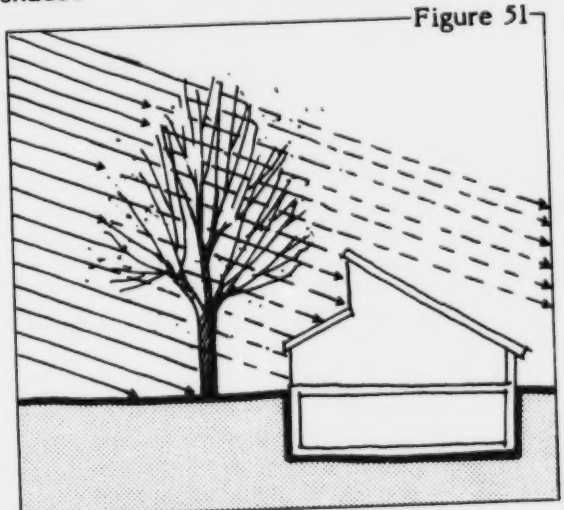
Figure 50B



Selection of deciduous trees depends upon type of building or space to be shaded

However, as mentioned above, the trunks and branches of deciduous trees will, to some extent, inhibit the penetration of sunlight during the winter as well. Therefore, deciduous shade trees planted on the south sides of buildings may effectively reduce the amount of solar radiation striking the building during the winter. With this in mind, trees with thin trunks and branches should be selected for these loations and should only be planted when they are necessary (18). The accompanying Figures 51 and 52 illustrate the relative percentage of sunlight penetrating a number of commonly used species. In the chart, the shaded area refers to the range of figures recorded for each of the species tested.

Figure 51

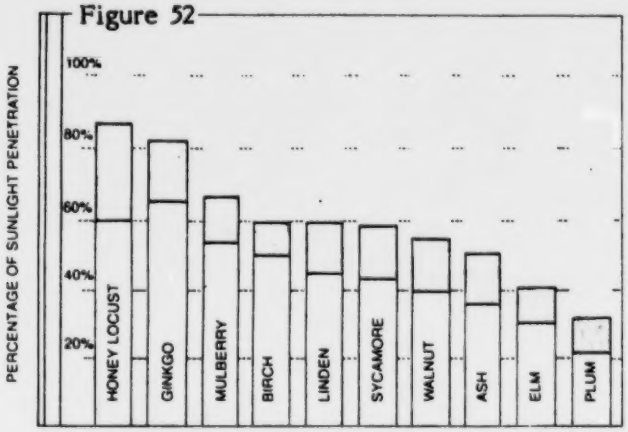


Branches and trunks of deciduous trees reduce intensity of solar radiation in winter

Due to their size and/or upright form, shrubs and coniferous trees have less shade value, especially during the middle hours of the day as shown in Figure 53A. However, during the morning and afternoon when the sun is lower to the horizon, these

(17) De Walle, 1980
(18) The Conservation of Energy in Housing, p. 27

Figure 52

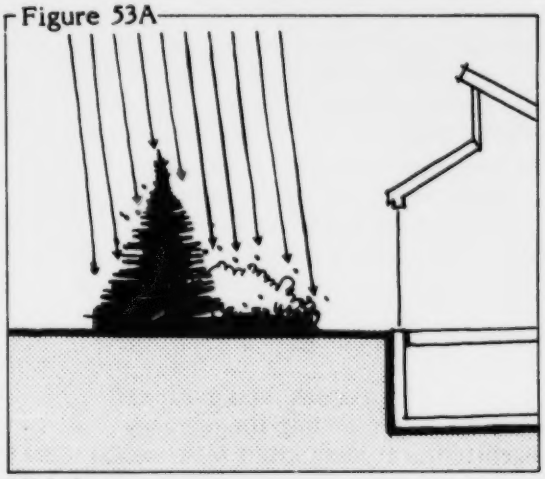


Relative Amount of Sunlight Passing through Deciduous Trees in Winter
(Source: Site Planning for Solar Access, p.96)

plants can be used very effectively, as shown in Figure 53B, to shade the east-west facades of buildings as well as certain types of outdoor spaces (19).

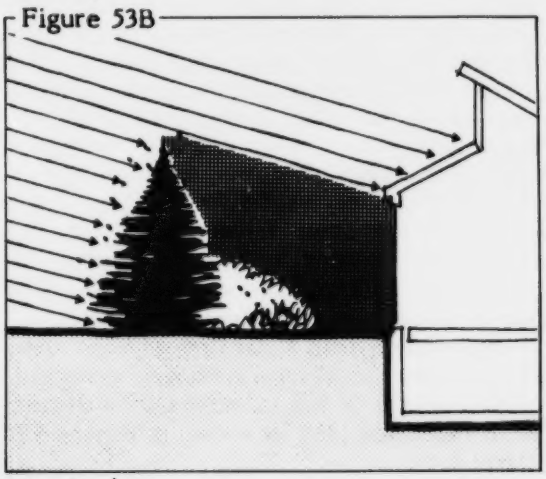
It has been suggested by some researchers that vines growing on the walls of buildings can reduce heat gain in summer. The leaves of the plant absorb and reflect sunlight and provide shade for the wall (20). The use of vines in this way would be particularly effective for protecting east and west facades from the morning and afternoon sun. (See Figure 54.)

Figure 53A



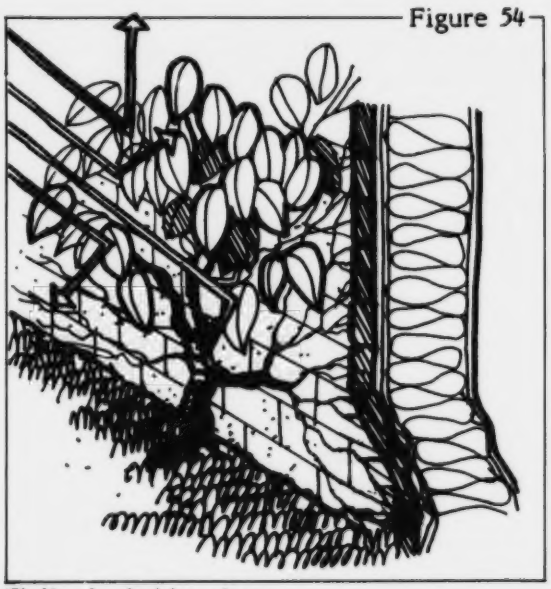
Mid-day

Figure 53B



Morning/afternoon

Figure 54

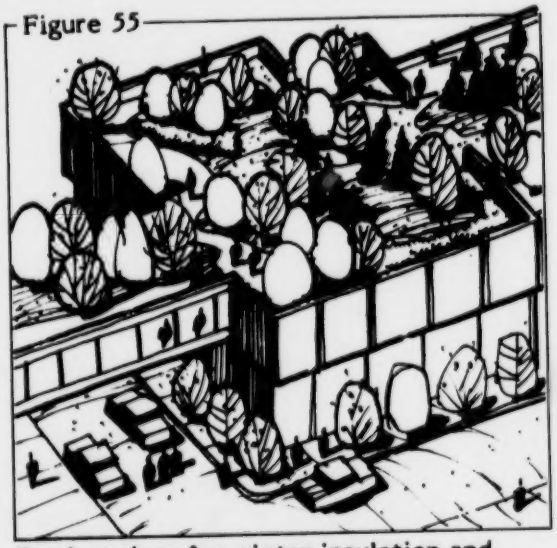


Walls shaded by vines

(19) Robinette, 1977, pp. 15 & 16
(20) Robinette, 1977, p. 46
The Conservation of Energy in Housing, p. 29

Trees and shrubs used in roof gardens also have considerable value in terms of energy efficiency. Since the summer noon sun is almost overhead, it is very difficult to shade the roof with trees planted beside the building. Therefore, plant materials on the roof itself, as shown in Figure 55, reduce heat gain by blocking the sun. Moreover, the soil of the roof serves as additional insulation as well as heat storage thus maintaining more stable temperatures within the building.

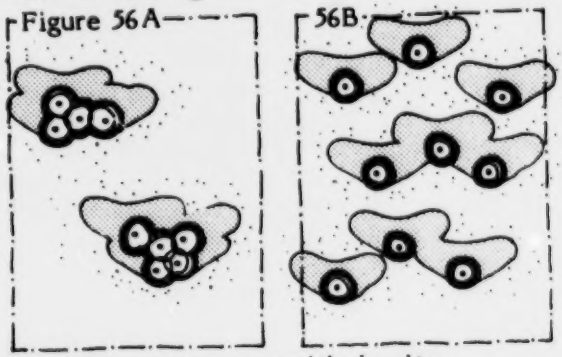
Figure 55



Roof gardens for winter insulation and summer cooling

Deciduous trees planted in groups will provide shade for large outdoor areas or building facades. To provide continuous shade over an outdoor area, trees can be planted such that the distance between them is no more than the average diameter of the tree's canopy. Trees which are lightly grouped will tend to shade each other rather than the ground beneath. Alternatively as spacing is increased the total area shaded will rise but if the spacing is too wide small separted pools of shade will result. Figure 56A shows clusters which are too tight, whereas 56B shows the effect of too wide spacing.

Figure 56A — 56B

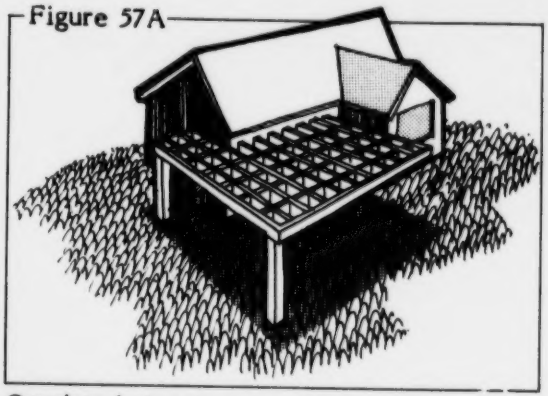


Shadow patterns vary with density and organization of plants

Walls, fences, and overhead structures are among the primary architectural elements which can be used to produce shade. Although walls and fences are used primarily as privacy screens and for property definition, they can be used to shade small spaces or building facades. Like shrubs, fences and walls are not usually very high and so are most useful in the early morning or late afternoon when the sun is low. Overhead structures, on the other hand, can be very useful for shading facades and outdoor spaces. When combined with vegetation, these structures, including trellises and pergolas, can provide almost as much shade as mature deciduous trees, however, overhead structures used on the south sides of buildings should be designed in such a way as to not interfere with winter solar radiation (21), as shown in Figure 57A through D.

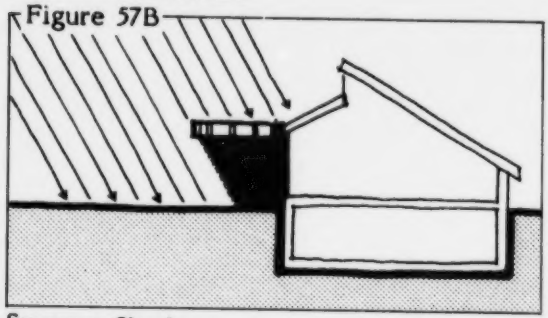
(21) Builder's Guide, p. 13
Robinette, 1977, p. 124

Figure 57A



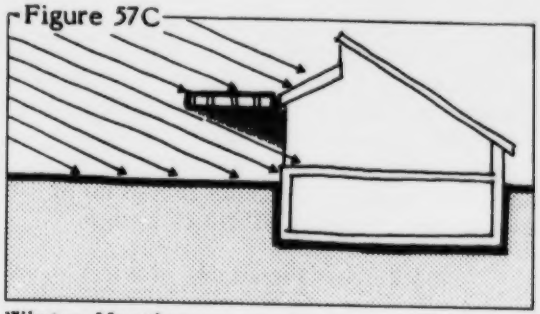
Overhead structure

Figure 57B



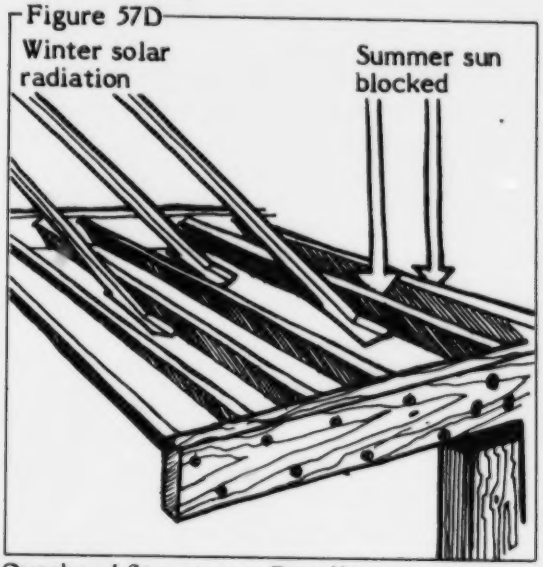
Summer Shade

Figure 57C



Winter Heating

Figure 57D



Overhead Structure: Detail

4.4 Wind

4.4.1 Introduction

Winds are complex both with respect to their causes and to their effect on the microclimate, particularly at the scale at which most environmental design work is done. There often seems to be very little relationship between the gusty turbulent ground level winds and regional wind pattens (1) as suggested by Figure 58.

Winds increase the rate of evaporation, lowering the temperature of moist surfaces but also move air masses from one place to another and so may cause a local increase or decrease in temperature thus affecting human comfort in outdoor spaces. In addition, wind can influence the quantity of energy needed to heat or cool a building by changing the heat transfer through the building envelope by more importantly by infiltration through every opening.

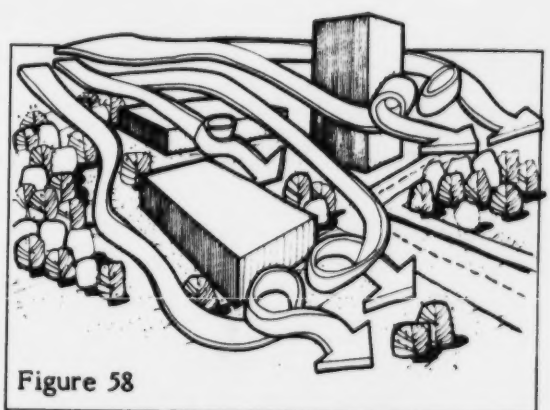


Figure 58

Turbulence in Complex Environments

(1) Energy Efficient Community Planning, p. 56

A good deal of the research on wind and wind controls relates to the agricultural problem of soil drifting, and it is difficult to relate the results to the urban mileu. More recently, research directed to wind problems in built up areas has been undertaken and the results should be of assistance in energy efficient design.

4.4.2 Principles of wind movement and control

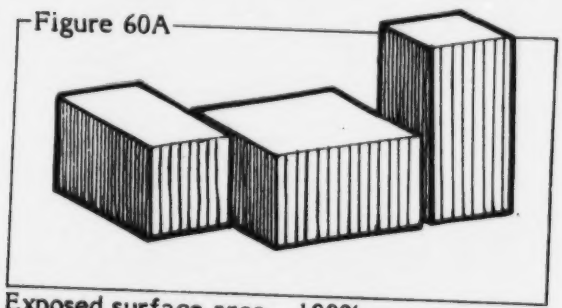
An understanding of the way in which wind moves over around and past the obstacles it meets is necessary to achieve control. Some of the basic patterns of interaction (2) are shown in Figure 59A-H.

Based on these patterns, there are four general methods of controlling wind: obstruction, filtration, guidance and deflection, and acceleration (3). In the following sections wind controls will be described in terms of their role in minimizing winter cooling effects and maximizing summer cooling effects.

4.4.3 Minimizing winter cooling effects

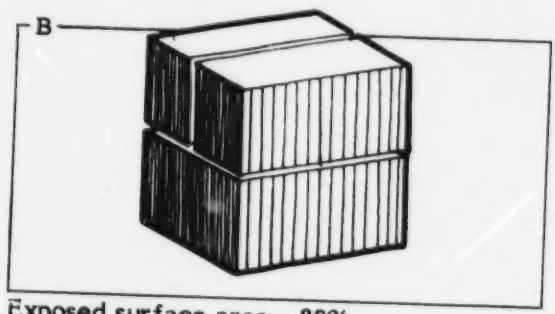
Recent research has emphasized increasing resistance to the cooling effects of wind through better design and construction and, to a lesser extent, through site planning and landscape design. One of the ways of accomplishing this is by reduction of the exposed surface area by the use of a more compact form (4) (Figure 60A and B) or by joining adjacent buildings (5)

Figure 60A



Exposed surface area - 100%

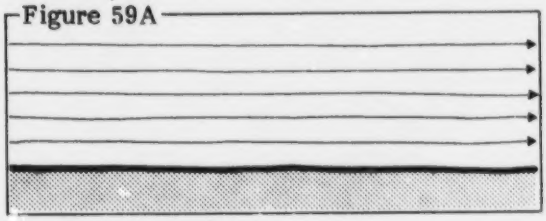
B



Exposed surface area - 80%
Compact forms reduce exposed surface area

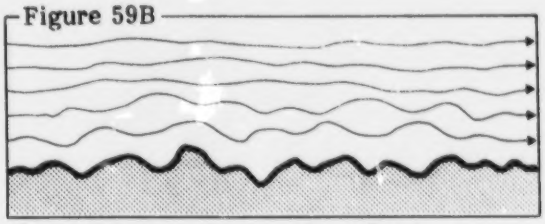
(2) Robinette, 1977, p. 21
(3) Robinette, 1977, p. 21
(4) Builder's Guide, P. 13
(5) Robinette, 1977, p. 124

Figure 59A



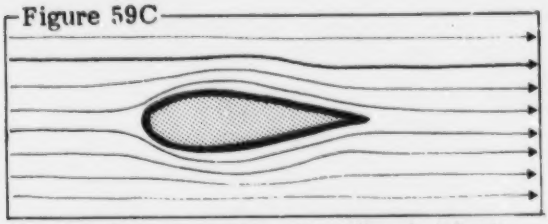
a) Smooth air flow

Figure 59B



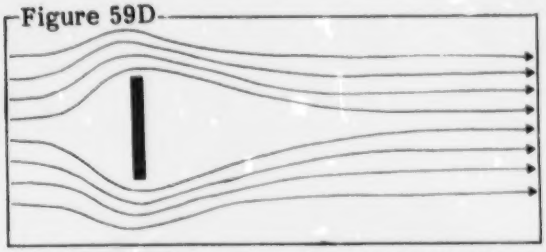
b) Air flow over a rough surface

Figure 59C



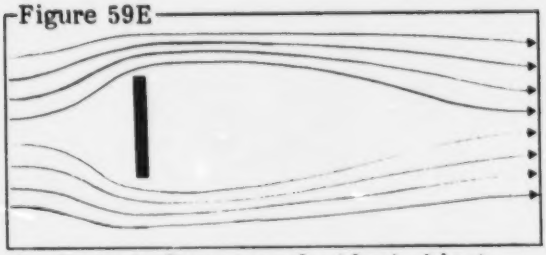
c) Air flow around a steamlined object

Figure 59D



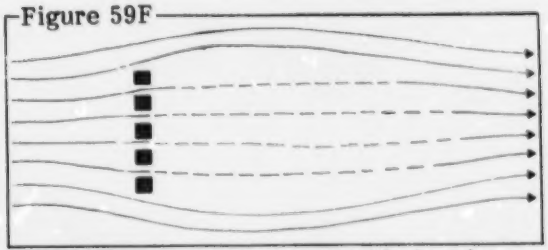
d) Slow air flow around a blunt object

Figure 59E



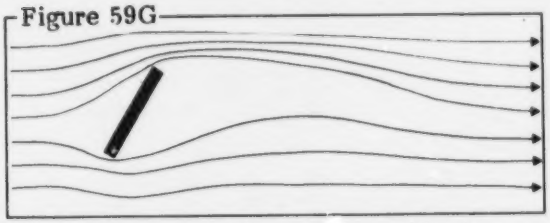
e) Fast air flow around a blunt object

Figure 59F



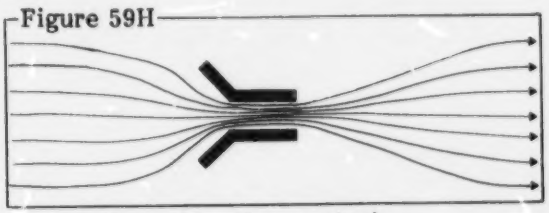
f) Air flow around a permeable barrier

Figure 59G



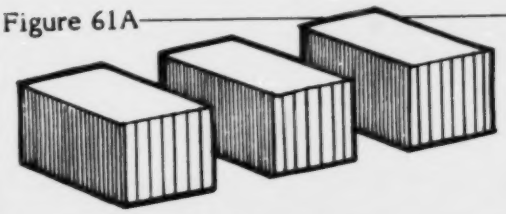
g) Air flow around an oblique object

Figure 59H



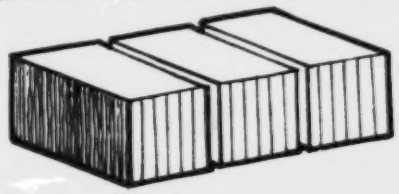
h) Air flow through a venturi

Figure 61A



Exposed surface area - 100%

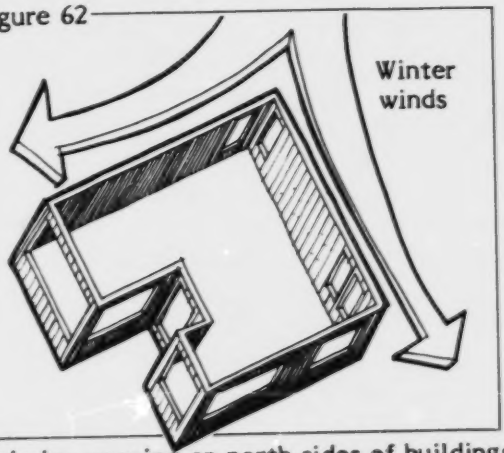
B



Exposed surface area - 66.6%
Joining adjacent buildings
reduces exposed surface area

(Figure 61A and B). Avoiding openings (6) on the windward side as shown in Figure 62 is another useful approach. Finally, more attention to structural details, in particular vapour barriers, and more effective seals on doors and windows is important (7).

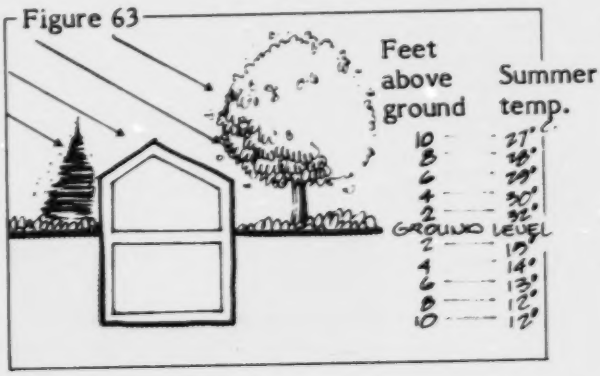
Figure 62

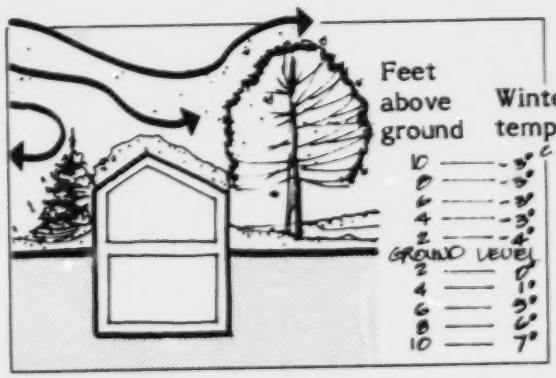


Minimize opening on north sides of buildings

The exposed surface area of buildings can be further reduced by utilizing the insulating and storage properties of soil. Due to its mass and low conductivity, soil tends to maintain temperatures which are more stable than those of the air above; minimum soil temperatures are higher in winter and maxima in summer are lower. The accompanying diagram 63 illustrates the relationship between air and soil temperatures at various depths. There are a number of ways in which energy efficiency of buildings can be increased by using this principle. Conventional buildings can be set more deeply into their surroundings and can have berms built up against the walls. The effect of both of these techniques can be increased when buildings are located on south-facing slopes. Depending upon the depth, the soil used in roof gardens can serve a similar purpose; the soil mass stores heat during the day and releases it slowly during the night thus maintaining more stable temperatures inside. The insulative value of each is most fully exploited in underground buildings in which only windows and doors are exposed to the air and the wind. Some of the possibilities are suggested in Figure 64A-C.

Figure 63





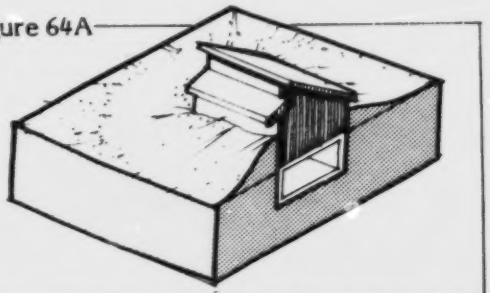
Effects of Earth on Temperature
(Source: Options for Passive Energy Conservation in site Design, p. 17)

It has been found through a series of simulation studies that the orientation of the building relative to the wind is extremely important. In 1975, Mattingly and Peters conducted wind tunnel tests using a group of four attached townhouses as the study model. In general, it was

(6) Energy Efficient Community Planning, p. 56

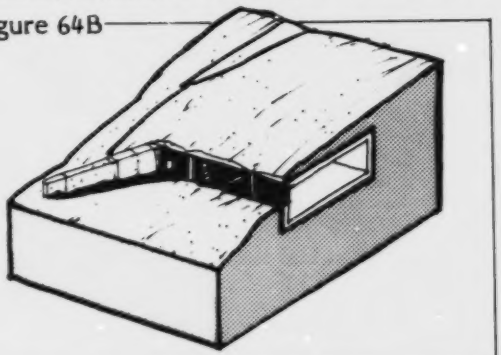
(7) Builder's Guide, p. 22

Figure 64A



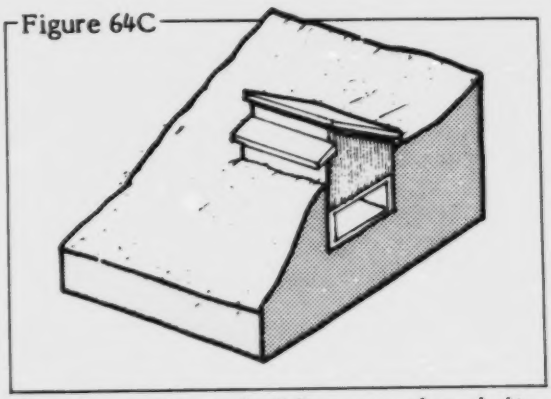
Berming against a building on a flat site

Figure 64B



Underground building built into a south-facing slope

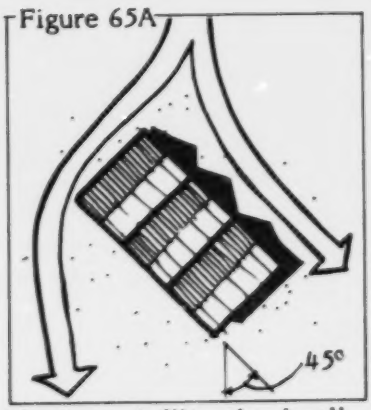
Figure 64C



Berming against a building on a sloped site

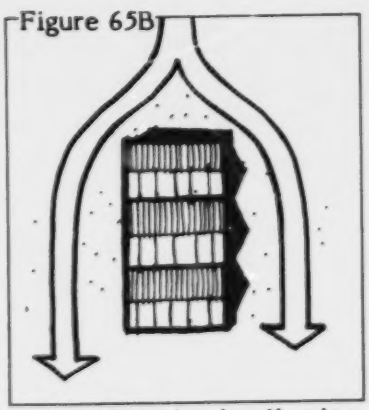
concluded that the amount of wind infiltration was directly related to the surface area of the walls exposed to the wind. In all cases, the end units, due to their exposed end walls, recorded higher rates of infiltration than interior units. However, the worst possible orientation was with the building turned 45° to the wind. In this position, infiltration in the end unit was 59 per cent more than when the front facade alone was facing the wind. Similarly, infiltration in the interior units was 15 per cent higher. The reason for this performance is clear from Figure 65A–C.

Figure 65A



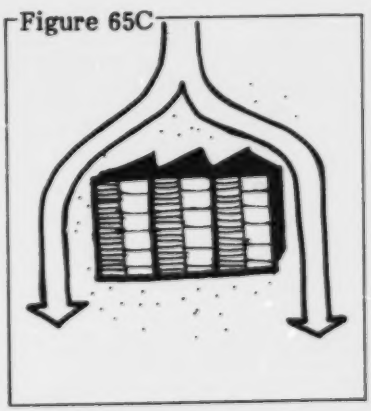
Maximum infiltration in all units

Figure 65B



High infiltration in all units

Figure 65C



The best orientation of the building was where the longitudinal axis was parallel to the air flow. Since this position provided the least amount of exposed wall surface, the rates of infiltration were reduced in all but one unit on the windward end of the group (8).

Apart from these architectural considerations, the most effective method of controlling wind is through the use of vegetation, walls and fences, and even buildings themselves as windbreaks. Important for protecting both buildings and outdoor spaces, windbreaks of different kinds have long been important features of the rural and agricultural landscape.

The planning and design of windbreaks requires careful analysis of wind patterns and site characteristics.

The degree and type of control provided by a windbreak are functions of its size, structure, density, and distance from the space or element to be protected. The following are the basic principles governing the effectiveness of various types of windbreaks:

(a) A blunt, vertical barrier causes marked decreases in wind speed on both sides, but the distance of influence (d) is much greater on the leeward side. The greatest reduction in wind speed occurs a short distance from the leeward side of the windbreak. (9).

(b) The distance of influence varies directly with the height (h) of the barrier. (10).

Figure 66A

Figure 66B

Effects of Terrain on Wind

Figure 67A

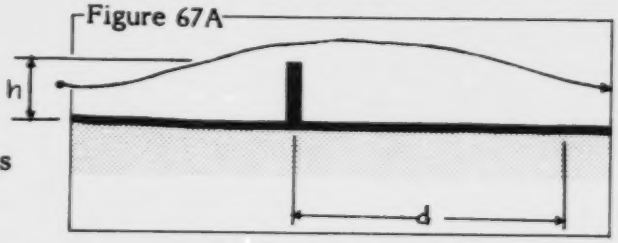
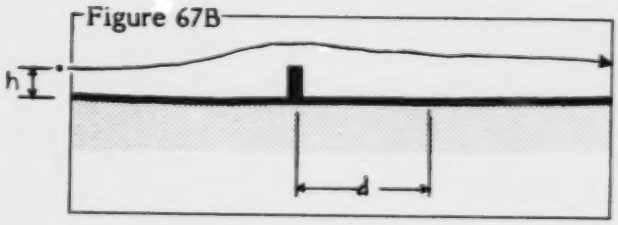


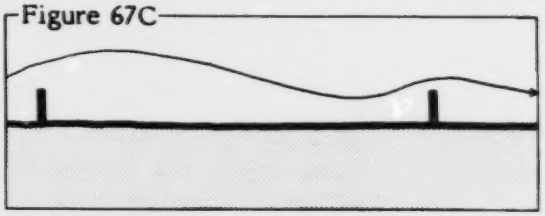
Figure 67B



(8) Mattingly and Peters, 1975, pp. 32-37
(9) Van der Linde, 1962, p. 162
(10) Tani, 1968, p. 44

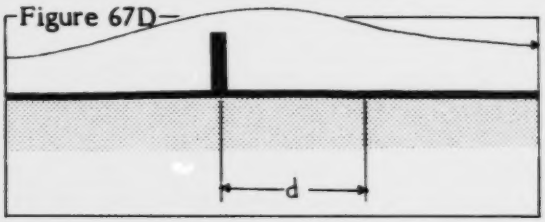
(c) Multiple barriers can serve to reduce overall wind speed if the barriers are not more than 10-20 barrier heights apart depending upon local circumstances. (11).

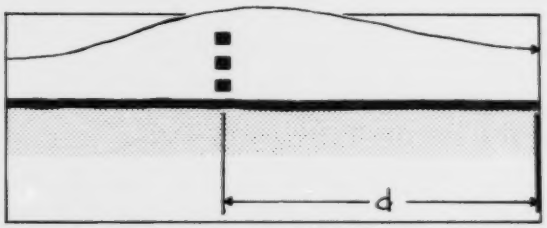
Figure 67C



(d) A permeable windbreak reduces the wind speed less than a solid one, but the distance of influence is greater. A permeable windbreak also causes less turbulence than a solid one. (12).

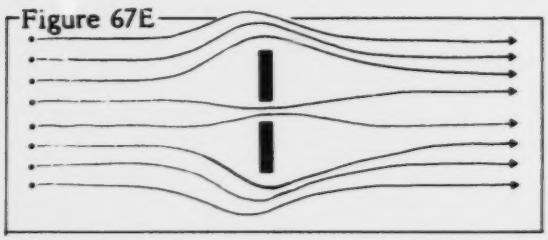
Figure 67D





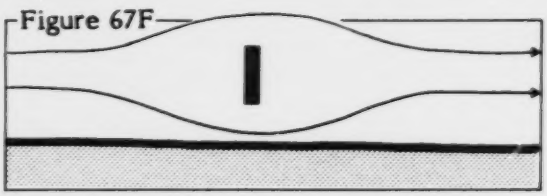
(e) The wind speed is increased through gaps in barriers and around the ends. (13).

Figure 67E



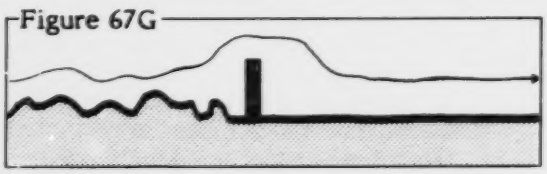
(f) The wind speed in increased under the bottom of barriers which are raised up off the ground. (14).

Figure 67F



(g) The influence of a windbreak is reduced if the terrain on the windward side is rough. (15).

Figure 67G



(h) Because it is more streamlined, a rounded barrier will have less effect on wind speed than a barrier with blunt faces. (16).

Figure 67H

(11) Geiger, 1965, p. 503
(12) Mattingly and Peters, 1975, p. 44
(13) Nageli, 1953, p. 82
(14) Gorshenin, 1934, p. 49
(15) Jensen, 1954, p. 38
(16) Robinette, 1977, p. 35

(i) The transverse dimension (td) of a barrier does not increase its effectiveness except inasmuch as the density is increased. In certain circumstances, the effective distance of influence on the leeward side may be reduced (17).

There are basically three groups of materials which have been used, either alone or in combination, for the development of effective windbreaks (Fig. 68A-H). The selection of one or all of these materials, including vegetation, architectural elements, and landforms, is based on the cost and availability of materials, the intrinsic effectiveness of the material, and the specific application for which the windbreak is required.

Vegetation is commonly used in windbreak development, especially in those rural areas where plant materials are readily available and easy to maintain and where there is adequate space to develop a barrier of sufficient density. However, vegetation can be used in many ways to control wind speed, therefore, can be effectively used in urban and suburban contexts as well.

The five (5) main criteria which govern the selection and use of plant material for windbreaks include form, density, seasonal variation, growth characteristics, and hardiness.

a) Form

The nature and degree of wind protection provided by a plant is determined to a large extent by its form. The major plant forms include trees (coniferous and deciduous), shrubs, vines, and ground covers. Because the particular effect of each plant on wind speed is different, they are often used in combination with one another or for very specific applications. (18).

Figure 67I

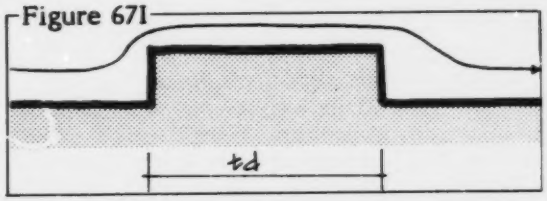
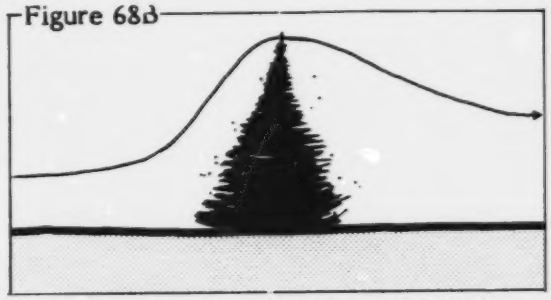


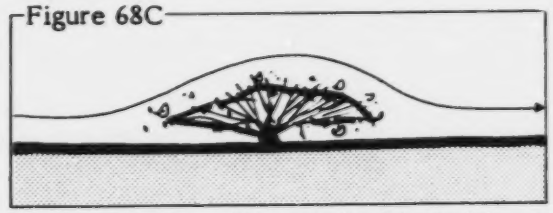
Figure 68A

Figure 68B



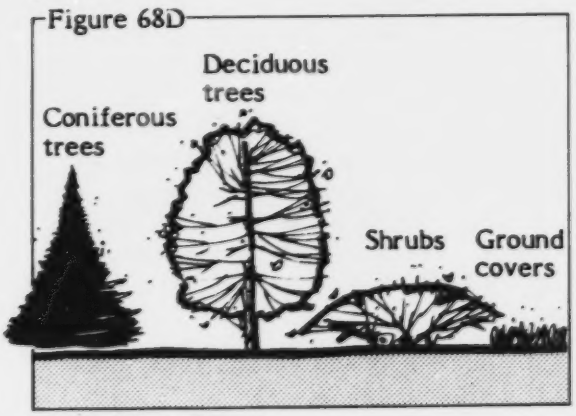
Coniferous Trees: Effective wind shelter at ground level

Figure 68C



Shrubs: Shelter effect limited by height of plant

Figure 68D



Major Plant Forms

(17) Robinette, 1977, p. 35
(18) Robinette, 1977, pp. 24 and 188

(b) Density

The ability of a plant to reduce wind speed is determined to a large extent by its density. The density of plants varies according to the number, size, and form of their leaves and branches. Plants with dense structures include Norway Maple, Norway Spruce, and Austrian Pine. (19).

(c) Seasonal variation

The ability of a plant to control wind may vary from season to season. This is particularly true with deciduous trees and shrubs which lost their leaves during the seasons when the windbreak is most needed. (20).

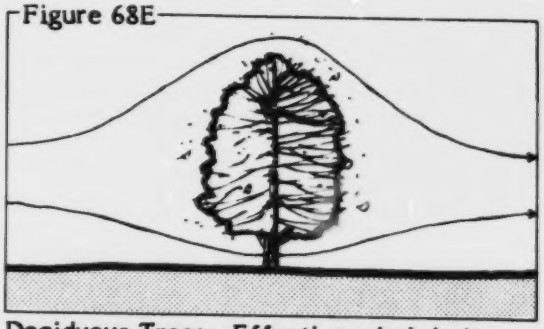
(d) Growth characteristics

The ability of plants to control wind changes as they grow. The design of vegetative windbreaks must allow for this by the use of plants of different growth rates in the understory. Figure 69 shows a series of sections through such a developing windbreak.

(e) Hardiness

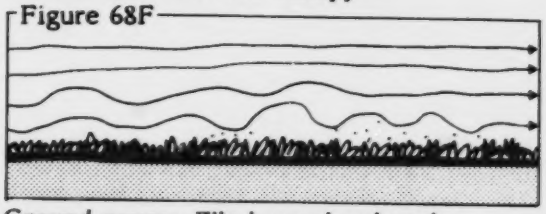
The ability of plants to survive the exposure to wind, snow loading, and temperature or moisture extremes is a measure of hardiness. For examples of plants hardy in the various climatic regions of Ontario, see Table 5.

Figure 68E



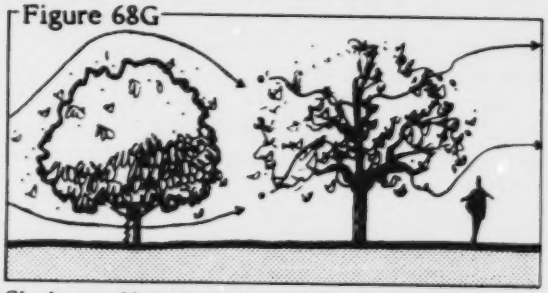
Deciduous Trees: Effective wind shelter above ground level, but wind may accelerate under the canopy

Figure 68F



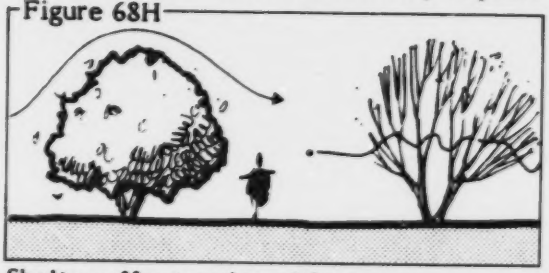
Ground cover: Wind speed reduced immediately above ground level

Figure 68G



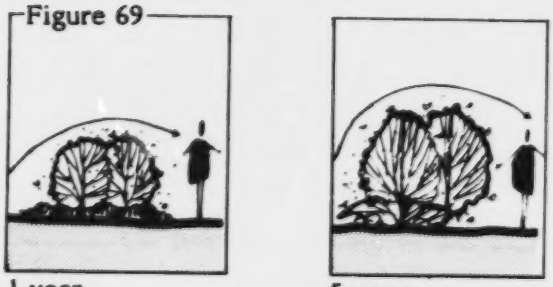
Shelter effects varies with density of plant

Figure 68H



Shelter effect varies with season

Figure 69



1 year 5 years 10 years 15 years

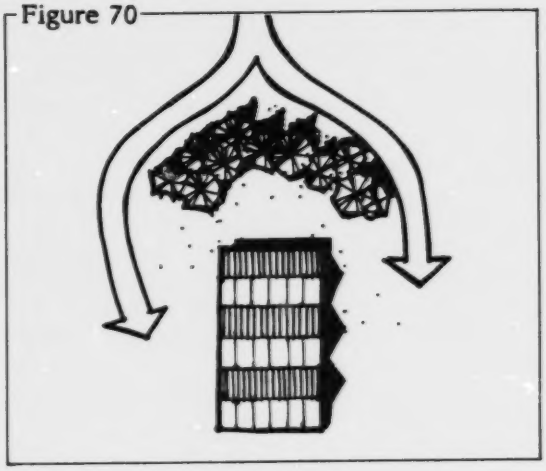
Windbreak management to optimize effectiveness over time

(19) Robinette, 1977, pp. 24 and 188
(20) Robinette, 1977, p. 22

There have been a number of studies conducted to determine the effectiveness of vegetative windbreaks. In these studies, the emphasis has been on the investigation of specific plant forms and upon the organization of the plants to form the windbreak.

Evergreen trees like Spruce and Pine generally provide the best wind protection primarily because they retain their foliage during the winter when wind protection is most needed. Mattingly and Peters, in the study cited above, found that a densely planted row of evergreen trees, as shown in Figure 70, resulted in a 60 per cent reduction in wind infiltration. In their study, the trees were equal in height to the building and planted upwind a distance equal to 1.5-2.5 times the height of the building. (21). Van Haverbeke determined that more than two or three rows of trees did not appreciably increase the effectiveness of the windbreak; the reason for this is that in dense plantings the interior trees tend to lose their lower branches. (22).

Figure 70



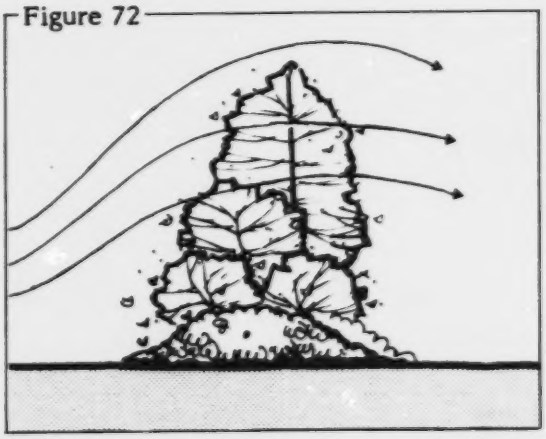
Windbreaks consisting of a large number of deciduous trees and shrubs (Figure 71) can also be effective. Olgyay estimated that trees without leaves were about 60 per cent as effective in reducing wind velocity as those with foliage. Although the velocity reduction is less, it may be effective over a larger area and the more open stand introduce less turbulence. Thus in total, a well planned windbreak made up of deciduous trees may be as effective as evergreens for certain applications. This is also generally true: windbreaks must be tailored to the local requirements if they are to be as effective as they can be. There are, however, some general principles.

Figure 71

Large numbers of deciduous plants can provide effective shelter, even in winter

Vegetative windbreaks have been found most effective when they are long (at least ten times the height). A mixture of species is more effective than a windbreak of just one variety to take advantage of the velocity reduction of evergreens close to ground level and the break up of streamline flow by deciduous trees toward the top. This is illustrated in Figure 72. Other

Figure 72



In order to lift wind up and over, the density of the wind break should be greatest near the ground

(21) Mattingly and Peters, 1975, p. 45
(22) Van Haverbeke, 1980

authorities (23) concur in this as openness near the ground may actually cause acceleration. Making the faces of the windbreak nearly vertical and using a mixture of species breaks up the air flow, whereas a dense sloping stand encourages streamline flow and little dissipation of energy. (24).

Where space does not permit a full windbreak, dense conifers like Cedar and Juniper adjacent to a building as in Figure 73 create insulating pockets of dead air (25). Vines growing on the wall may also be useful by increasing the depth of the air film covering the wall surface (26).

Fences and walls can be used as windbreaks either alone (27) or as an aid during the growth of vegetation. Some of the ways in which fences can be used along (Figure 74) or in combination with trees are suggested by the accompanying sketches (Figure 75). Instead of the slanted horizontal louvres of Figure 74C, vertical slats can be used and one report (28) states that such a fence gave less turbulence and protected more area than any of the other designs tested.

Buildings also act as windbreaks, protecting spaces around them and each other (29) as shown in Figure 76. However, they may also create turbulence and this in turn can increase infiltration (30). In a typical situation, the air velocity in the narrow gaps between buildings may be substantially above the average wind speed (31) but if trees can be planted in these spaces this affect may be reduced. Artificial structures which are relatively permeable such as trellises and pergolas may perform a similar function.

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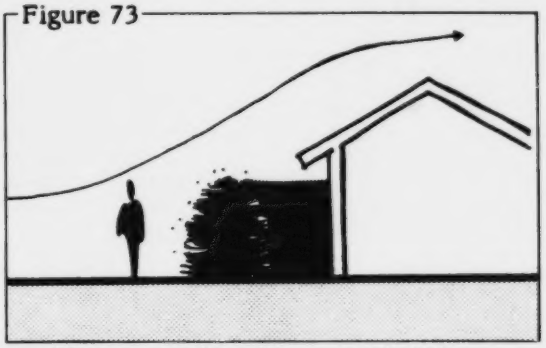
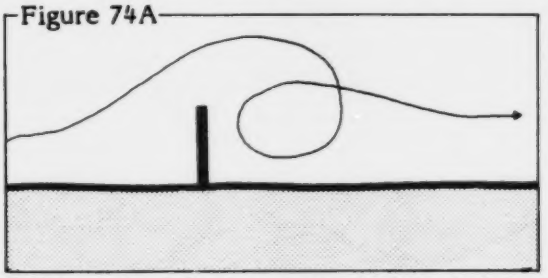
(23) Robinette, 1977, p. 35
(24) Options for Passive Energy Conservation in Site Design, p. 82
(25) Robinette, 1977, p. 53
(26) Furuta, 1978
(27) Mattingly and Peters, 1975, p. 41
(29) Mattingly and Peters, 1975, p. 41
(30) Energy Efficient Community Planning, p. 58
(31) Mattingly and Peters, p. 44

Figure 73



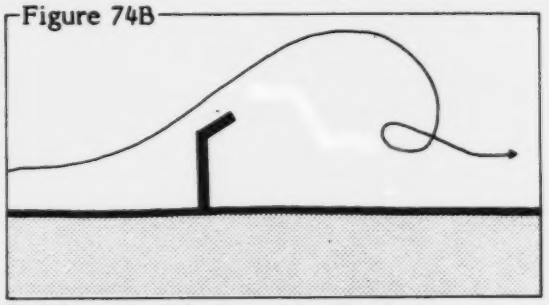
Coniferous shrubs adjacent to buildings create "dead air" space

Figure 74A



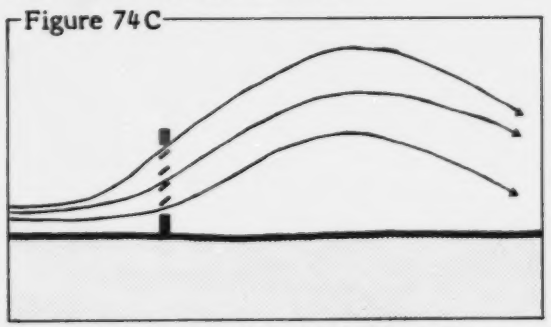
Solid vertical fence creates high turbulence

Figure 74B



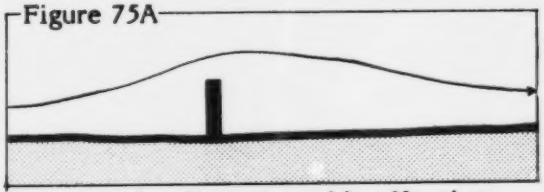
Solid vertical fence with tilted top increases sheltered distance

Figure 74C



Permeable fence with slanted louvres directs wind flow upwards which minimizes turbulence

Figure 75A



Fences and walls can provide effective wind shelters in small spaces

Figure 75B — 1 year

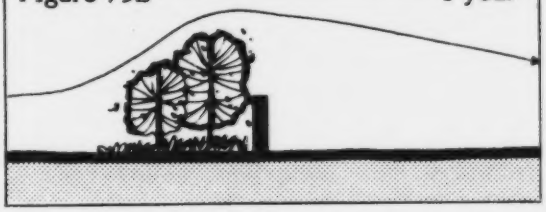


Figure 75C — 5 years

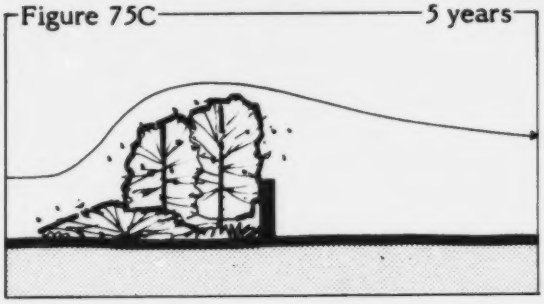


Figure 75D — 10 Years

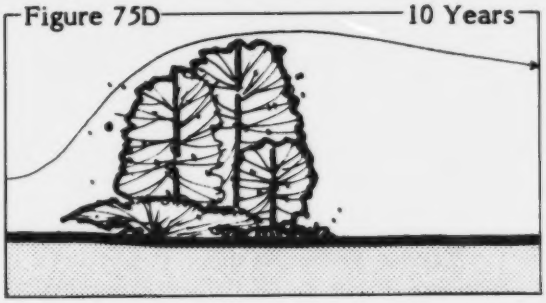
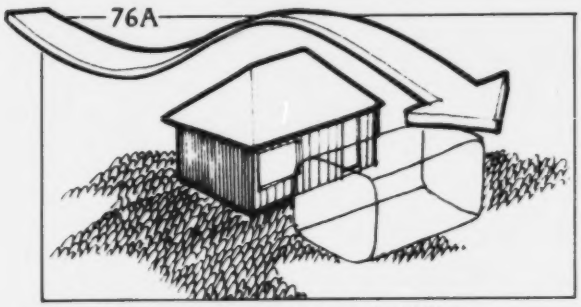
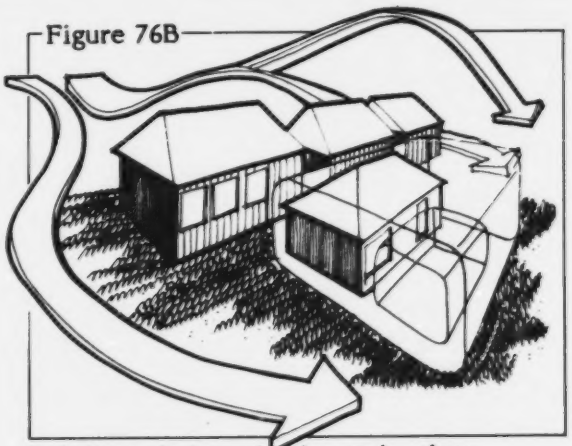


Figure 76A



Outdoor area sheltered by building

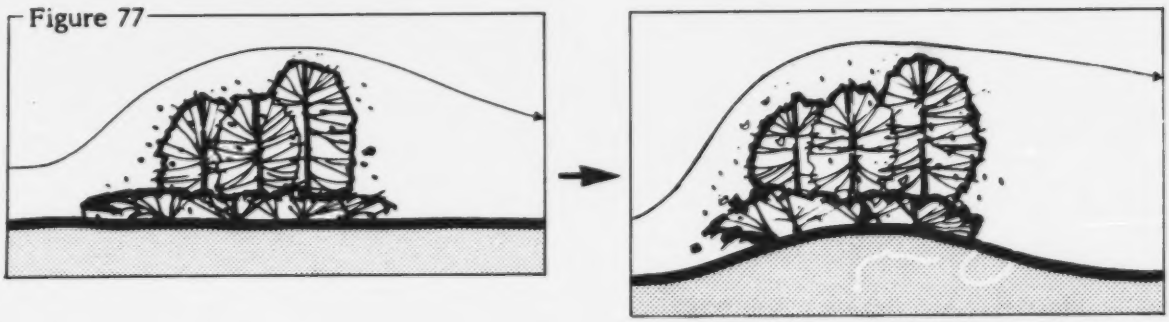
Figure 76B



Buildings sheltered by each other

Landforms can provide windbreaks but, except to raise the effective height of vegetation as shown in Figure 77, they are rarely high enough and too streamlined to be of great value. Natural features (Figure 78) may, however, be very effective and their presence could influence site selection and building placement.

Figure 77



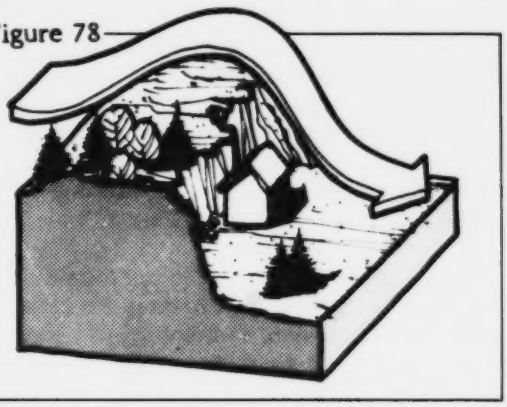
Landforms increase the shelter effect of plants

4.4.4 Maximizing summer ventilation

Although protection from winter winds is a more general problem in Ontario, summer breezes are not only pleasant in themselves but tend to keep insects away from spaces exposed to them. Breezes affect indoor conditions less in summer than in winter, but infiltration of warm air into conditioned space is a cause of energy loss in summer just as it would be in winter (32). Other authorities would prefer to take advantage of the costing effect of the air movement, and hence, reduce the need for conditioning (33).

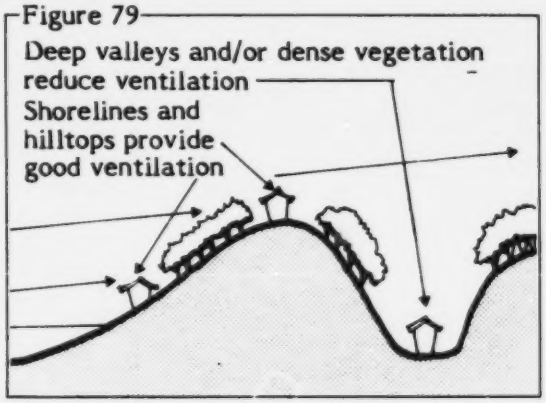
Some of the considerations in site selection to obtain the advantages of natural ventilation in summer are suggested in Figure 79. Winds can be guided or even accelerated by placement of buildings but the optimum arrangement for wind from one direction may be undesirable when it shifts. Figure 80 illustrates this dilemma.

Figure 78



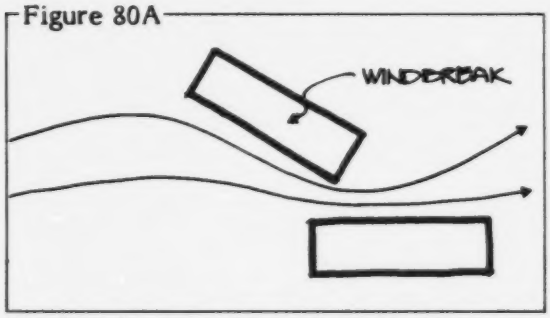
Sites can be sheltered by large abrupt landforms

Figure 79



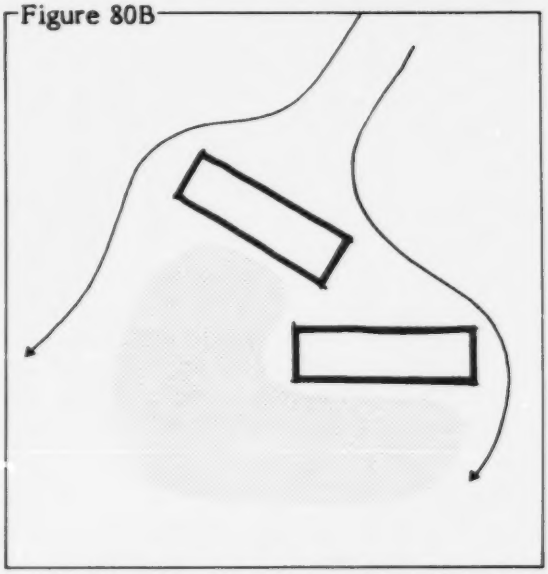
Site selection to maximize summer ventilation

Figure 80A



Windbreaks can guide and accelerate breezes from one direction

Figure 80B



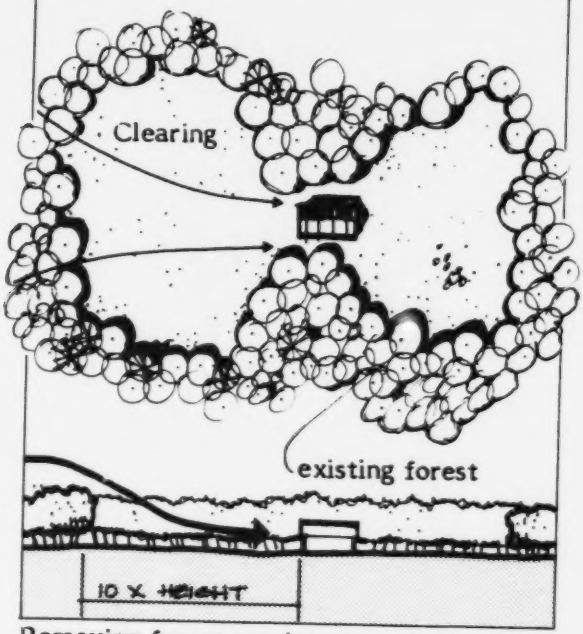
. . . but may block all breezes coming from other directions

(32) Moffat, 1980, p. 84
(33) Wallace, McHarg, Roberts and Todd, 1973, p. 25

If by good fortune the direction of summer and winter prevailing winds is different enough a windbreak may be able to do double duty. The velocity of channelled wind may be increased at some points of the site and it is at these that a building should be located (34) as seen in Figure 81.

Clearing of trees to open up a channel for air movement may be effective and this effect could be achieved by suitable orientation of a roadway. Some of these points are illustrated by Figure 82A-B. (35).

Figure 82A

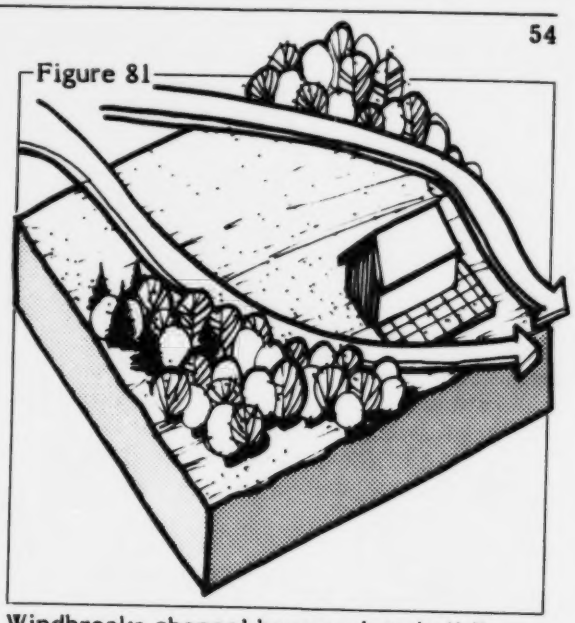


Removing forest can increase ventilation at ground level

Care must be taken not to block the channel on the exit side; breezes must leave as well as enter the area. Figure 83 shows the design error and the solution (36).

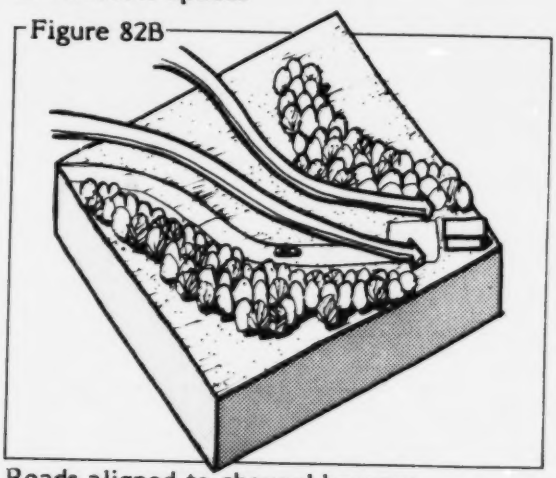
If there are turbulent winds of no well defined direction, deciduous trees open at the bottom may act to maintain air flow close to the ground regardless of its direction (38).

Figure 81



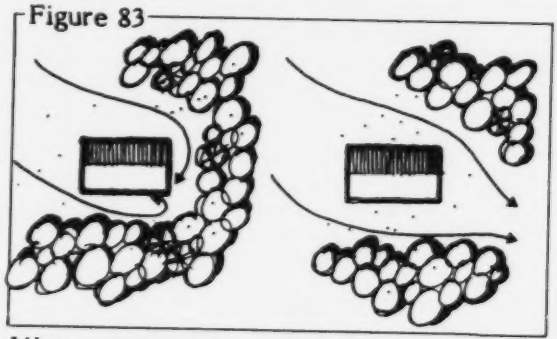
Windbreaks channel breezes into buildings and outdoor spaces

Figure 82B



Roads aligned to channel breezes

Figure 83



Allow summer breezes to flow through the site

(34) Wallace, McHarg, Roberts and Todd, 1973, p. 25

(35) The Conservation of Energy in Housing, p. 25

(36) Builders Guide, p. 17; White, 1953

(38) Cost Effective Site Planning, p. 4
Wallace, McHarg, Roberts and Todd, 1973, p. 25

Given a high degree of co-ordination between landscape development and building design, the amount of ventilation and direction of air movement inside a small building can be controlled to some extent. The sketches of Figure 84 illustrate the possibilities while those of Figure 85 show in plain view how the building placement combined with suitable plantings can favourably affect summer ventilation.

Figure 84A

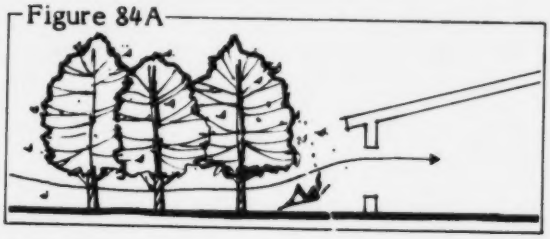


Figure 84B

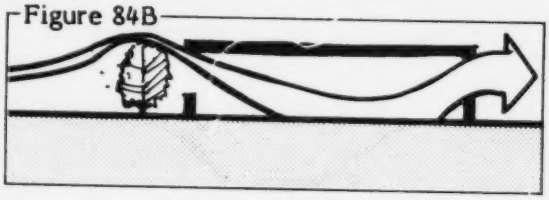


Figure 84C

Figure 84D

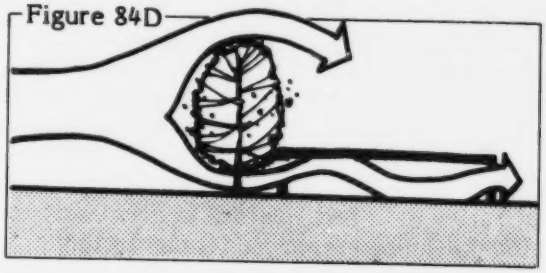
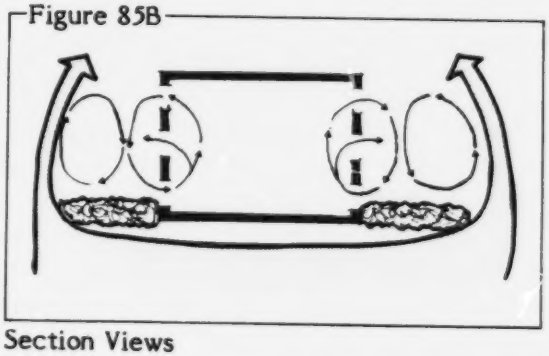


Figure 84E

Effects of plants on air flow through a small building

Figure 85A

Figure 85B



Section Views

4.5 Air Temperature

4.5.1 Introduction

Human comfort is, of course, greatly affected by air temperature and this in turn is influenced by various aspects of the physical environment. Due to the mixing action of surface winds, these tend to have their effect over relatively large areas and one may speak of the 'heat island' associated with urban development or the moderating influence of a large body of water. Terrain may also play a part as does vegetation. These aspects are considered briefly below.

4.5.2 Factors Affecting Air Temperature

4.5.2.1 Terrain

Air being a fluid is subject to the laws of fluid mechanics and cool dense air will flow downward displacing warmer air at the bottom of a slope. This can result in significant decreases in temperature at the top of a plateau and in the valley below with warmer temperatures in between. Some idea of the mechanism at work and the results are shown in Figures 86 and 87. Differences in temperature as great as 6 to 10°F have been recorded (1) due to this effect which is most pronounced in the absence of vegetation which tends to reduce the rate of change of temperature and to slow the air flow.

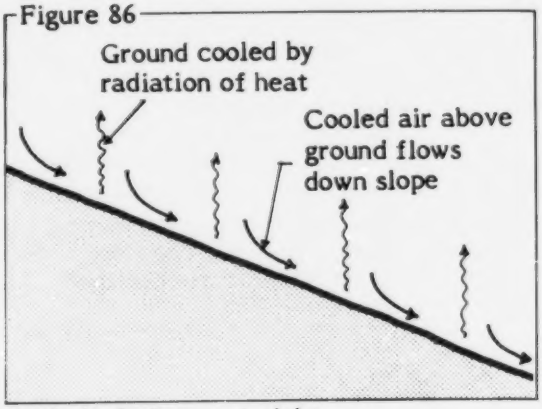
4.5.2.2 Water bodies

Large rivers and lakes can change in temperature only slowly. They thus reduce summer maximum and raise winter minimum temperatures. In addition to these seasonal effects they influence temperatures on a daily basis as well by essentially constant day and night temperature as compared with those of adjacent land masses. Some temperature data for southern Ontario in Figure 88 illustrates the moderating effect of the Great Lakes on the range of mean July temperatures. The effect is greatest in the lee of the water body (2).

4.5.2.3 Vegetation

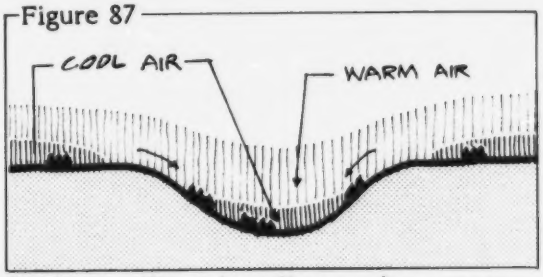
Forest cover reduces air temperature both by shading the ground beneath it and also by the evaporative cooling associated with transpiration. One author (3) estimates that a 21 m shade tree evaporates up to 100 gallons of water per day which he argues has the cooling effect of five room air conditioners operating for 20 hours. While the effect due to a single tree would soon be dissipated by surface air movement that under continuous forest cover would be retained.

Figure 86



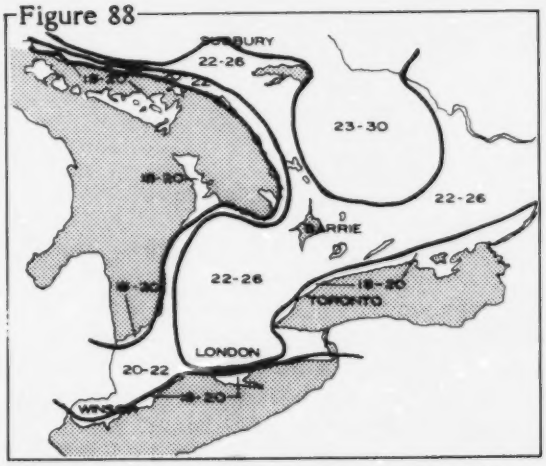
Cool air drainage at night

Figure 87



Cool air collects in valleys and on upper plateaus

Figure 88



Water bodies modify temperatures over adjacent land masses
(July mean daily range)

(1) Mecklenberg, p. 100
(2) Robinette, 1977, pp. 61-62
(3) Federer, 1976

At night the forest acts as a blanket and reduces the radiation from the ground surface. Thus, with reduced daytime gains and night losses, the daily variation is reduced greatly (4) (Figure 89). Temperature differences between forested areas and adjacent open lands of 5 to 13°F have been (5) measured, and are shown in the curves of Figure 90.

4.5.2.4 Urbanization

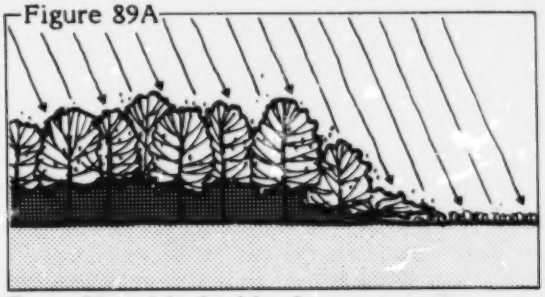
The heat island affect of cities results from increased heat storage, reduced ventilation and outflow from all heated structures. Paved surfaces and building components lose heat more slowly than soil and help to maintain air temperatures as night falls. The frictional drag of buildings and other urban features restrict the rate at which this pool of warm air is replaced (8). Some of the effects of urbanization on various climatic parameters are given in Table 6.

Table 6

	Comparison with rural environment
Contaminants:	
condensation nuclei and particulates;	10 times more
gaseous admixtures	5 to 25 times more
Cloudiness:	
cover;	5 to 10% more
fog, winter;	100% more
fog, summer	30% more
Precipitation:	
totals;	5 to 10% more
days with less than 5mm;	10% more
snowfall	5% less
Relative Humidity:	
winter;	2% less
summer	8% less
Radiation:	
global;	15 to 20% less
ultra-violet, winter;	30% less
ultra-violet, summer;	5% less
sunshine duration	5 to 15% less
Temperature:	
annual mean;	0.5 to 1.0°C more
winter minima (average);	1 to 2°C more
heating degree days	10% less
Wind speed:	
annual mean;	20 to 30% less
extreme gust;	10 to 20% less
calms	5 to 20% more

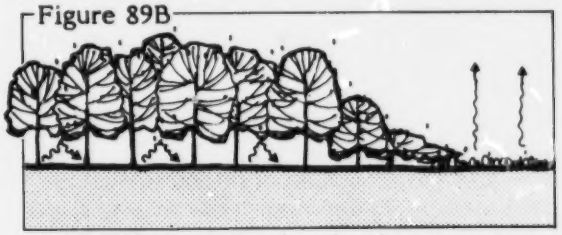
Average Changes in Climatic Elements Caused by Urbanization
(Source: Laidlaw, p.7)

Figure 89A



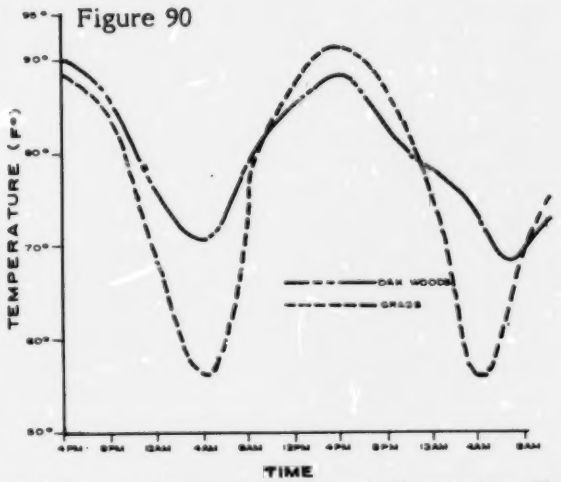
Day: Heat blocked by forest canopy

Figure 89B



Night: Heat retained under forest canopy

Figure 90



Modifying Effects of Different Vegetation Types
(Source: Landscape Planning for Energy Conservation, p.50)

(4) Robinette, 1977, p. 46
Federer, 1976
(5) Kittridge, 1948, pp. 57-58
(8) Laidlaw, p. 6; D'Agostino, p. 40; Geiger, p. 492

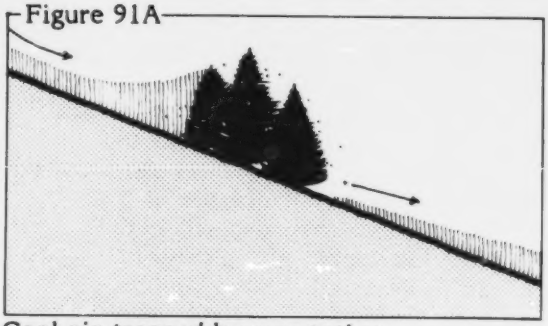
4.5.3 Modifying Air Temperature Through Landscape Planning

It is difficult to assign precise results to attempts to modify air temperature by landscape planning and more research in this area is needed. For example, while the cool air flow down a slope cannot be stopped, some researchers feel that it can be guided and directed by strategically placed vegetation, walls, fences and similar components. These concepts are illustrated by Figures 91A-B-C.

Other authors feel that cool air drainage is more a matter of site selection than site development. Plateau or valley sites may be cooler than those at mid slope (9).

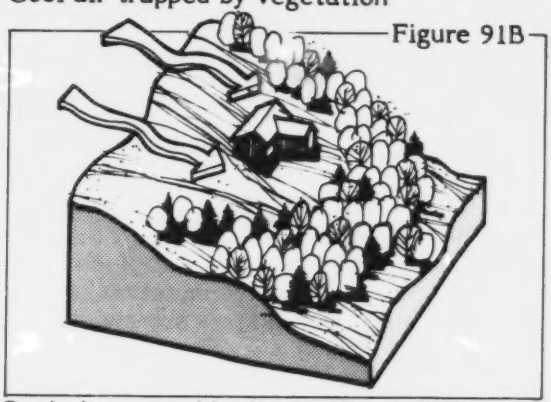
While even small water bodies may be aesthetically attractive, their influence on temperature is small. However, some research (10) indicates useful effects from ponds and fountains due to evaporative cooling or due to the air movement induced (11). There are similar reservations with repect to beneficial effects claimed for vegetation such as temperature reductions of 3.5°C in small (50 to 100 m) green spaces below those in built-up areas (12). Another study (13) showed that afternoon temperatures in narrow tree-lined streets were 5° or 6° lower than on broad avenues, although the effect was considered negligible by another (14) working on similar problems. There is general agreement that isolated trees have no measurable effect while forested areas do, so that the 60 or 70 per cent vegetative cover of urban areas probably has influence (15). There is, of course, no difference of opinion with respect to the beneficial effects due to shading from direct solar radiation. Figure 92A-C.

Figure 91A



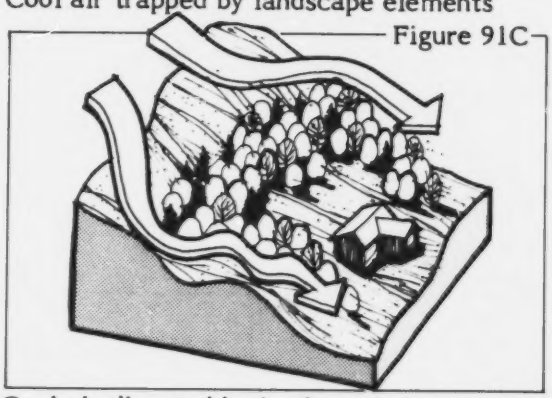
Cool air trapped by vegetation

Figure 91B



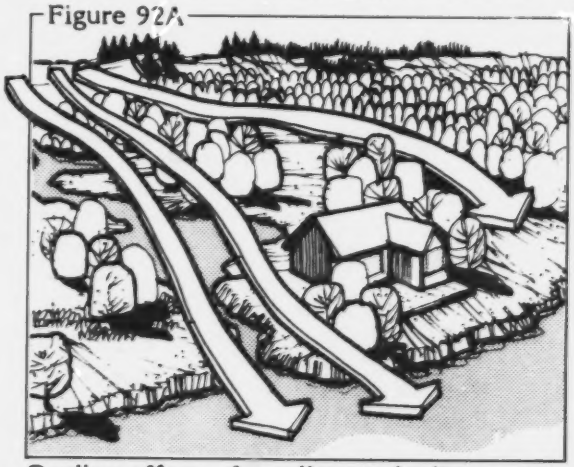
Cool air trapped by landscape elements

Figure 91C



Cool air directed by landscape elements

Figure 92A



Cooling effect of small waterbodies rapidly dispersed by the winds

(9) Robinette, 1977, p. 142
(10) Robinette, 1977, p. 142; Cost Effective Site Planning, p. 47
(11) Campbell, 1978, p. 27
(12) Bernatzky, 1977
(13) Federer, 1976
(14) Heisler, 1974
(15) Herrington, 1976

4.6 Humidity

4.6.1 Introduction

Humidity is important to human comfort because of its effect on the rate of evaporation from the skin surface and also because it affects the insulating value of clothing. However important it may be, there is little that can be done about it by site planning or development. The discussion which follows is based upon the limited experimental work and theoretical considerations aimed at control of humidity in the microclimate.

4.6.2 Modifying Humidity

Manipulation of sources of evaporation and control of on-site ventilation are the tools by which the humidity levels of a microclimate must be controlled, if at all. An increase in humidity may be achieved by developing lakes, ponds, and fountains and by retarding the run-off of rain water (1) while restricting the movement of air, particularly at low levels, through the site as much as possible (2).

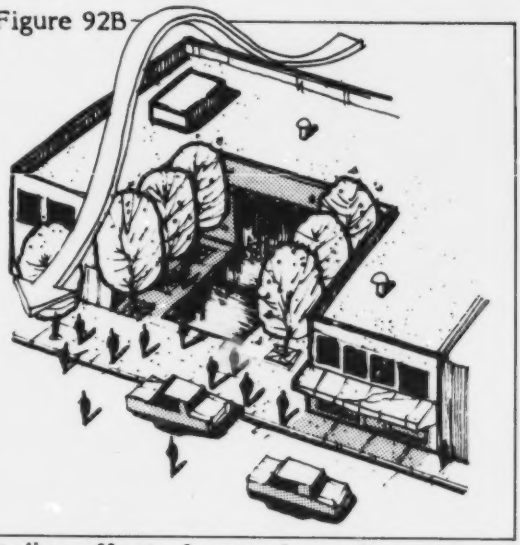
Conversely, if humidity is to be reduced, the reverse of this procedure should be followed, encouraging ground level ventilation and eliminating or reducing water surface. (3).

A schematic representation of the hydrologic cycle is shown in Figure 93 whilst Figures 94A and B illustrate the techniques of humidity control by regulation of water surfaces and ventilation.

The vegetation of large forested areas has an undoubted effect on humidity, due in part to transpiration. Grass, too, draws moisture from the ground; an acre of turf is estimated to lose about 2400 gallons of water per day (4).

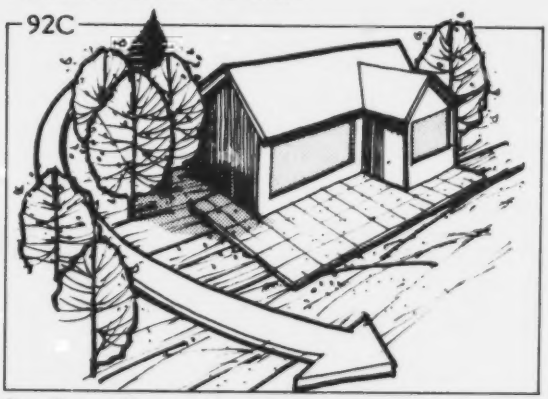
(1) Robinette, 1977, p. 144; Cost Effective Site Planning, p. 43
(2) Herrington, 1975
(3) Robinette, 1977, p. 144; Cost Effective Site Planning, p. 47
(4) Robinette, 1972, p. 86

Figure 92B



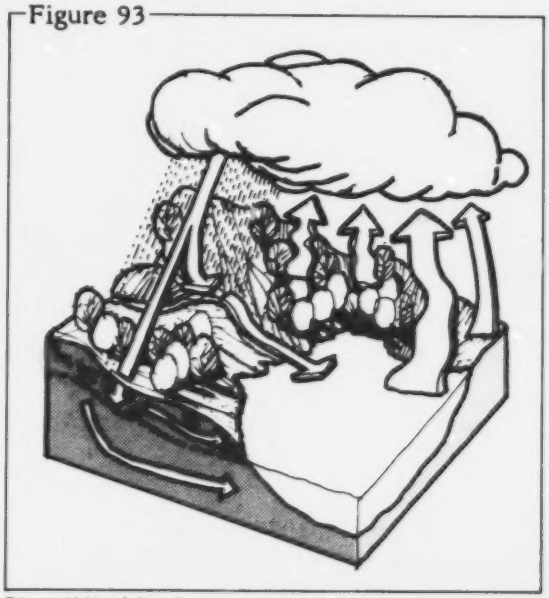
Cooling effect of water in small spaces Sheltered from the wind

92C



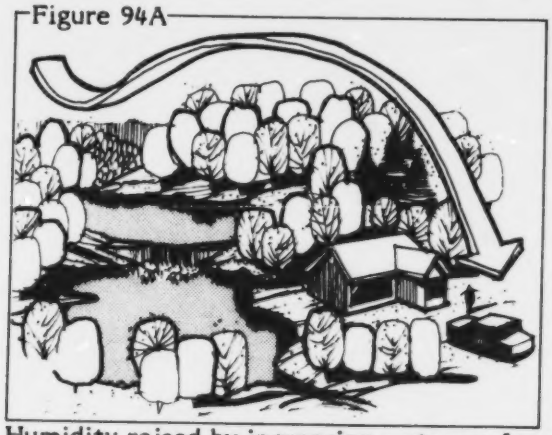
Cooling effect of vegetation is rapidly dispersed by the wind

Figure 93



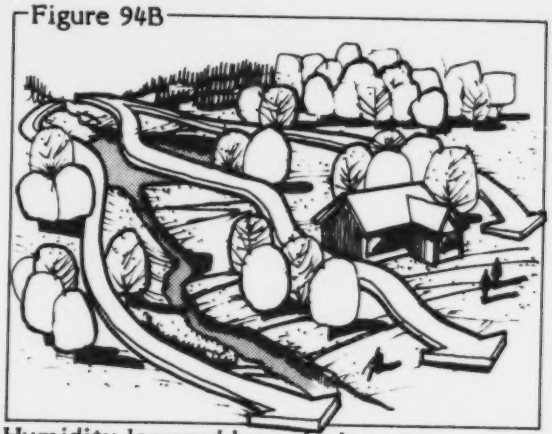
Simplified hydrological cycle

Figure 94A



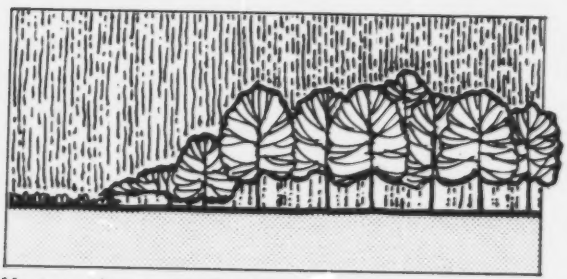
Humidity raised by increasing water surface and restricting its movement

Figure 94B

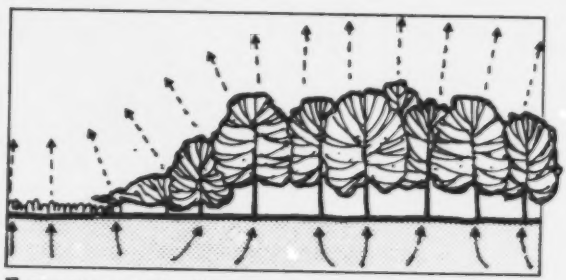


Humidity lowered by reducing water surface and increasing ventilation

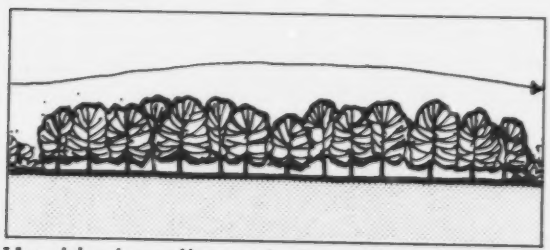
The blocking of solar radiation combined with the effects of transpiration increase humidity under the forest canopy (5), but many observers (6) doubt that there are observable effects under typical urban conditions. Considering an urban area as a whole, the converse is probably true, measurements have found humidity levels there 2 to 8 per cent less than the surrounding countryside (7). Figure 95.



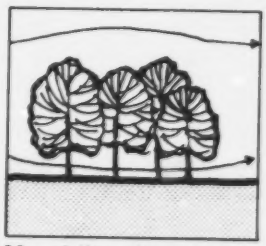
Vegetation retards the flow of precipitation into the soil



Evapotranspiration



Humid microclimate in large forested areas



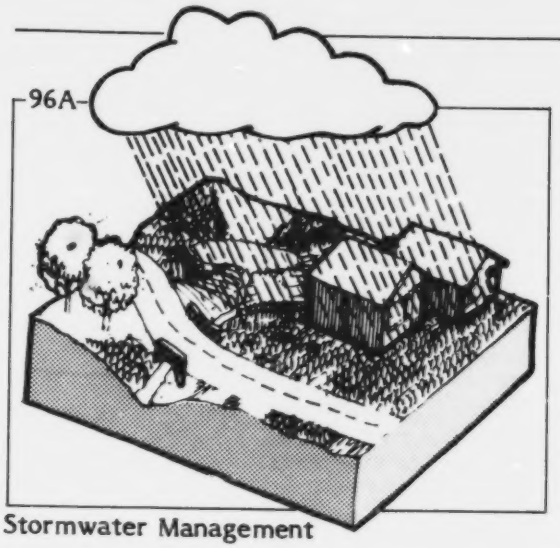
Humidity dispersed by wind

Humidity retained in a greenhouse

Figure 95

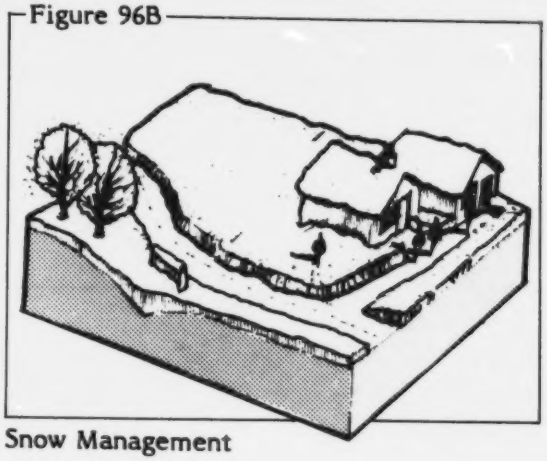
(5) Robinette, 1977, p. 40
(6) Heisler, 1976; Herrington, 1975; Plumley, 1977
(7) Laidlaw, p. 7

96A



Stormwater Management

Figure 96B



Snow Management

4.7 Precipitation

4.7.1 Introduction

The management of stormwater, snow, and, to a limited extent, dew and frost is an important concern of site planning, particularly as it relates to energy usage. Some of the factors to be considered are discussed below and are illustrated in Figures 96A and B.

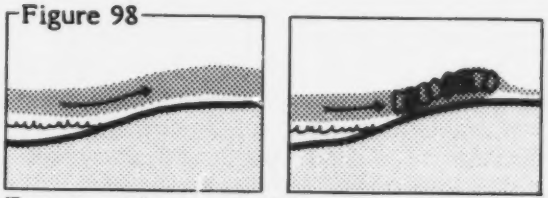
Dew - Dew may restrict early morning or late night use of some outdoor areas particularly if there is vegetation which can radiate heat to the open atmosphere (1). On the other hand, since the dew forms on the coolest vegetation, tree cover may protect the ground beneath as shown in Figure 97. This may make outdoor areas usable earlier in the morning or later at night (2).

Figure 97

Dew collects on the tops of trees rather than on the ground under them

The leaves of forest trees lose heat rapidly by radiation and if they cool below the temperature of the surrounding air water may condense out on them. Due to the large surface area of leaves and twigs, forests may accumulate ten times as much dew as adjacent open areas. They are so effective in this respect that some coastal areas in Japan have been kept forested to reduce the severity of sea-fogs which invade the coast (3) (Figure 98).

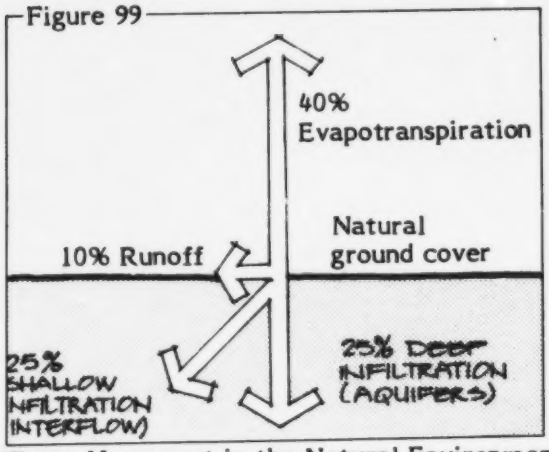
Figure 98



Forest used to control sea fogs

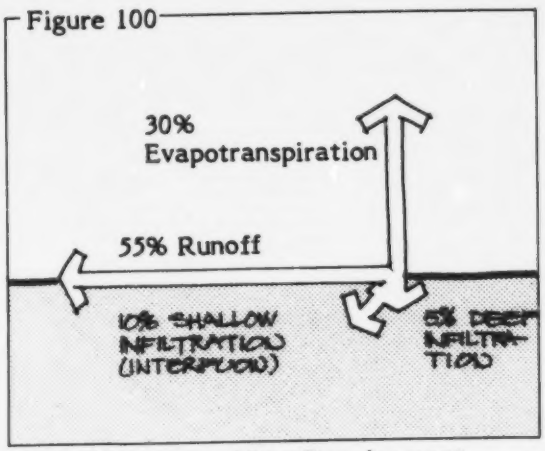
(1) Kittredge, 1948, p. 122
(2) Robinette, 1977, p. 39
(3) Hoover, 1962, p. 72

Figure 99



Water Movement in the Natural Environment

Figure 100



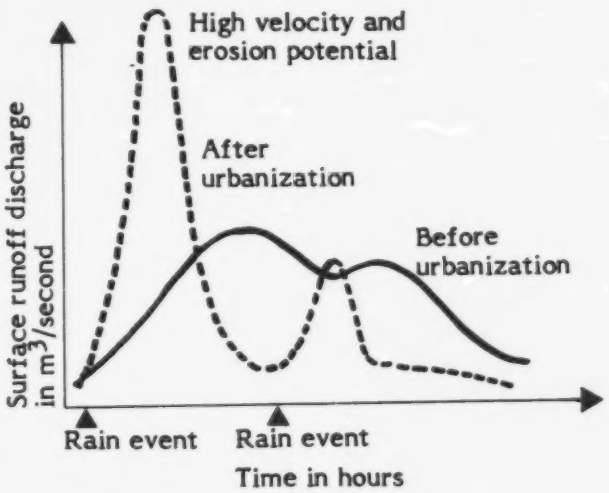
Water Movement After Development
(Source: Costs and Benefits of Environmental Planning Practices, p.36-37)

Frost, the sub-freezing equivalent of dew, forms in similar areas and under similar conditions. It is more likely at the top of plateau areas or in low valleys than at the intermediate heights for the reasons pointed out above (4).

Rain - Although rain itself cannot be controlled at the microclim[illegible] level, an appropriate design reponse .o rainfall is critical. Under natural conditions relatively little of an average rainfall contributes to surface run-off (5) whereas almost all that falls on a built-up area does so (6). These differences are illustrated in Figures 99 and 100 and in the curves of Figure 101.

The discharge of stormwater into sanitary sewers was an accepted practice when sewage treatment was the exception since the fate of both forms of waste was the same. With modern sewage treatment, stormwater would overload the system and flush untreated sewage to the discharge area. To avoid this, costly parallel systems have had to be constructed and these create new problems in erosion, and downstream siltation. The annual costs of building and maintaining these systems and repairing the flood damage caused by them were estimated in 1975 at almost 5 billion dollars for the United States (7).

Figure 101



Typical Hydrographs
(Source: Costs and Benefits of Environmental Planning Practices, P.37)

(4) Robinette, 1977, p. 7
(5) Costs and Benefits of Environmental Planning Practices, p. 36
(6) Costs and Benefits of Environmental Planning Practices, p. 37
(7) Costs and Benefits of Environmental Planning Practices, p. 39

The alternative solution is to make maintenance of the water flow characteristics of the site a development requirement (see Figure 102A-C). This requires no increase in run-off so that any problems are localized rather than being passed on to others. Control methods fall into four categories (8) some of which are illustrated in Figure 103.

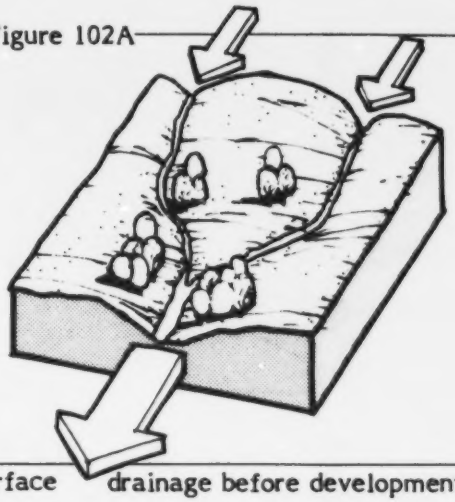
a) The amount of paving and other impervious surfaces can be reduced in order to permit a greater portion of the stormwater to seep into the ground.

b) Vegetation can be increased and/or retained in order to maximize the amount of stormwater consumed and stored by the plants.

c) Stormwater can be held on the site in temporary storage areas from which water is gradually released or in permanent lakes and ponds which can be used for irrigation and recreation.

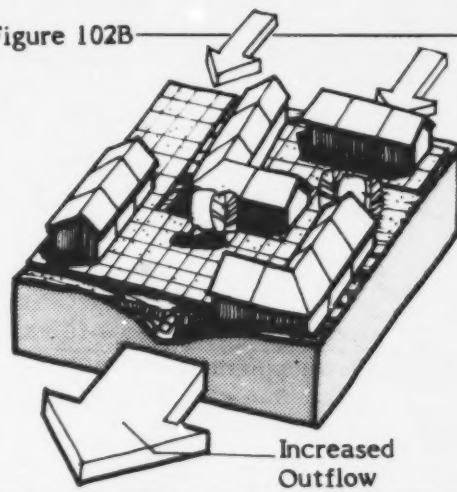
d) Stormwater can be drained to temporary or permanent storage areas by means of surface collection systems and/or low volume underground systems.

Figure 102A



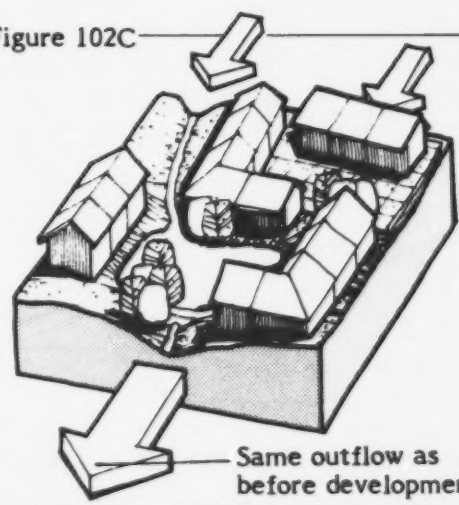
Surface drainage before development

Figure 102B



Surface drainage after conventional development

Figure 102C

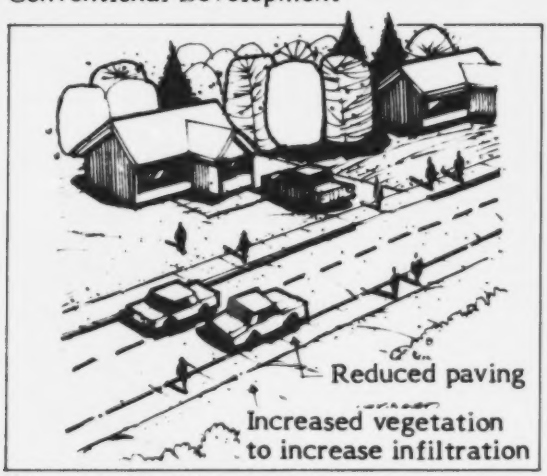


Surface drainage after "zero increase" development

(8) Costs and Benefits of Environmental Planning Practices, p. 40

Conventional Development

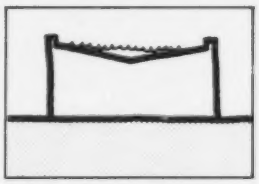
Conventional Development



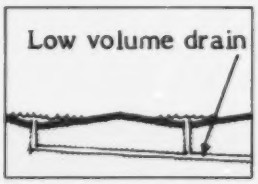
Alternate Development

Alternative Development: Reduce paving by clustering buildings

Storage/Recreational lakes

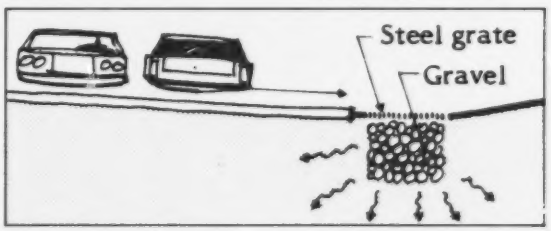


Temporary storage on flat roof

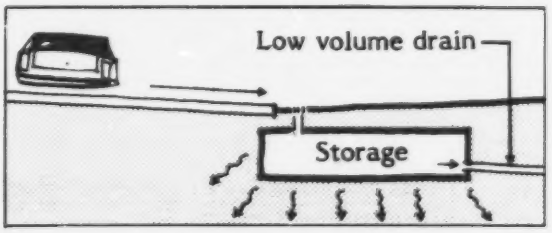


Temporary storage in parking lot

Temporary storage in remote park areas



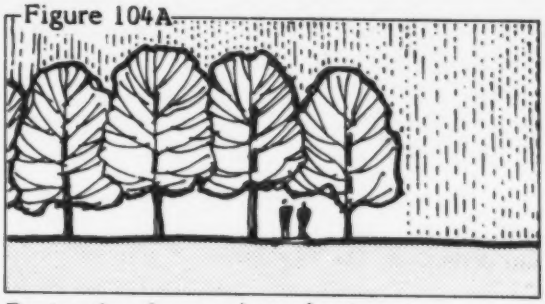
Cascade storage stream



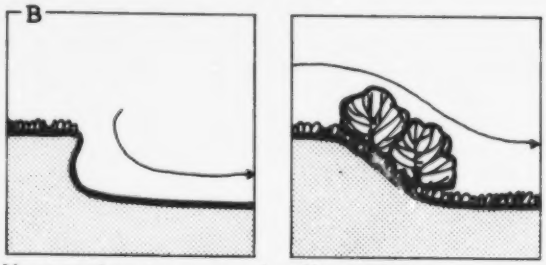
Temporary storage in surface drainage swales

Vegetation on the site may reduce the amount of water reaching the ground as suggested by some authors (9) but this is effective for light showers only which do not in general contribute much to runoff. The principal advantage of vegetation is as a control of soil erosion as runoff water is conducted to some temporary storage (11). Grass and other ground cover may also encourage infiltration and in any case are the most effective vegetation for erosion control (12) (see Figures 104A-D).

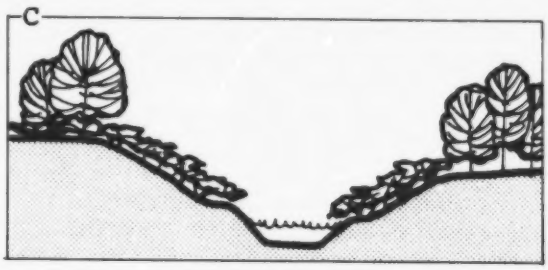
Figure 104A



Protection from rain under trees

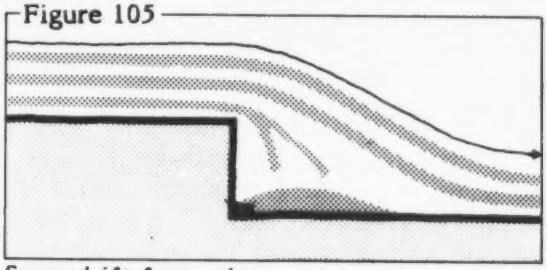


Vegetation to control soil erosion



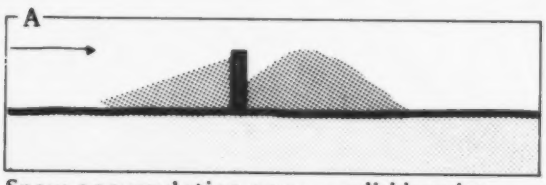
Snow - Snow will accumulate whenever and wherever wind velocities drop. It, thus, builds into drifts around windbreaks, buildings, fences, walls, and certain landforms leaving other areas bare or nearly so (Figure 105). Some of the locations prone to snow accumulation are illustrated in Figure 106A-E.

Figure 105

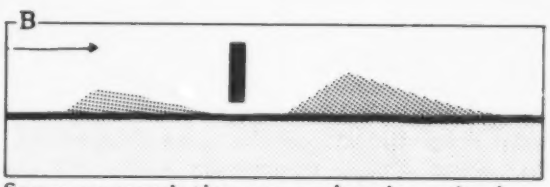


Snow drift formation

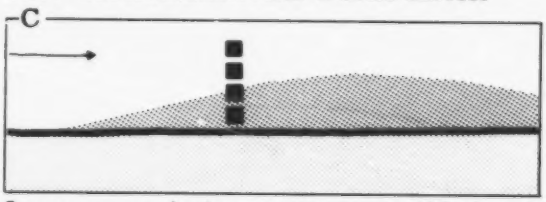
Figure 106



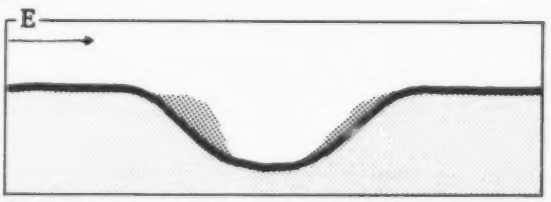
Snow accumulation near a solid barrier



Snow accumulation near a barrier raised off ground



Snow accumulation near a permeable barrier



Snow accumulation near land forms

(9) Robinette, 1977, p. 39
(11) Kittredge, 1948, p. 311-354
(12) Steiner, 1972

Permeable barriers are more effective than solid ones in accumulating snow. About 50 per cent openings have been found to be optimal. This is typical of the design used to protect highways.

There is an empirical relationship between the length of drift and the height and density of the barrier.

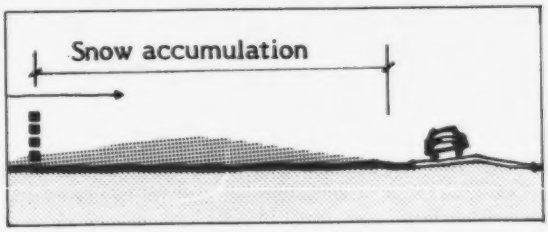
$$L = \frac{36 + 5h}{k}$$

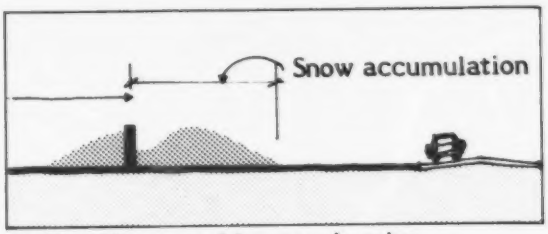
where L = length of drift (feet)
h = height of barrier (feet)
k = a constant related to screen density (at 50 per cent k = 1 at 70 per cent k = 1.28)

Placement of a snow barrier is important; a location 5 to 10 times the barrier's height upwind from the area to be protected will allow space for the accumulation, rather less is satisfactory if the barrier is solid. Typical desposition of snow around various barriers is shown in Figure 107A-E.

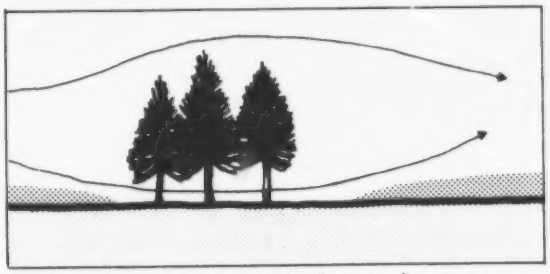
It was pointed out above that some placement of buildings might create areas of high wind velocity and so increased heat loss due to infiltration. The same effect can be turned to advantage to keep certain areas, such as driveways, relatively clear of snow (17).

Where snowfall amounts make mechanical removal necessary, proper site design can help to reduce the costs. A first step is to minimize areas to be cleared; to make use of wind to blow some places clear and to provide adequate space for equipment to work and to pile snow where it will not cause additional drifting are other considerations. The placement of snowpiles relative to shading by buildings and vegetation will affect the rate of melting in spring. Late melting is desirable for ski slopes, toboggan runs and rinks but not for areas wanted for early spring use. Figure 108A-F illustrates a number of these points.



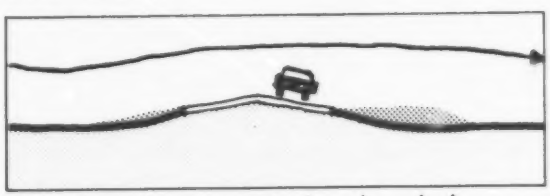


Solid and permeable snow barrier



Reduced snow accumulation under trees with open understory

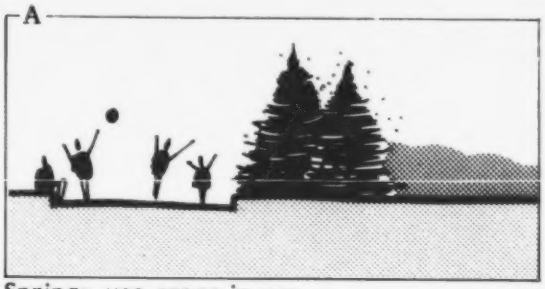
Snow Control



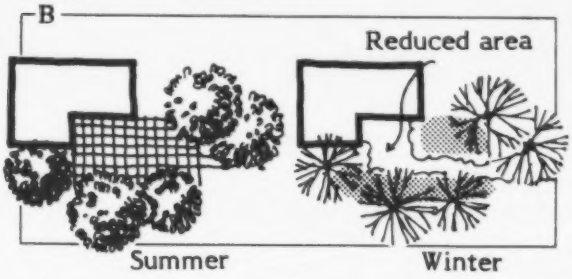
Raised roadway swept clear by wind

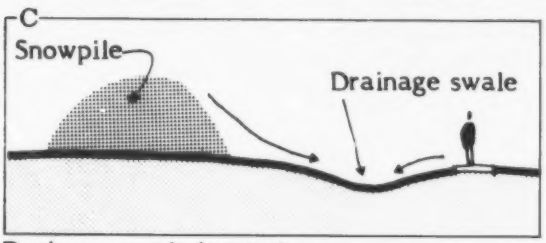
Figure 107A-E.

(17) Robinette, 1977, p. 44

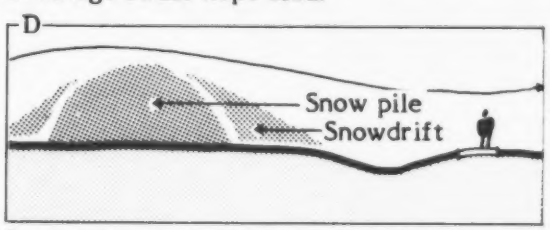


Spring: use areas in sun

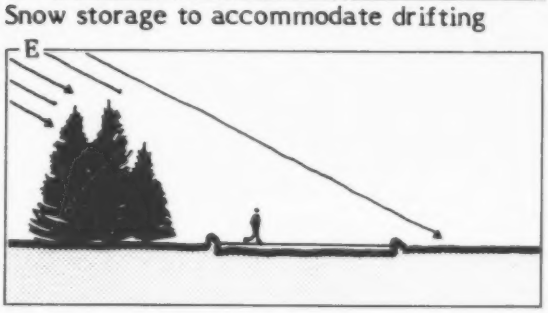


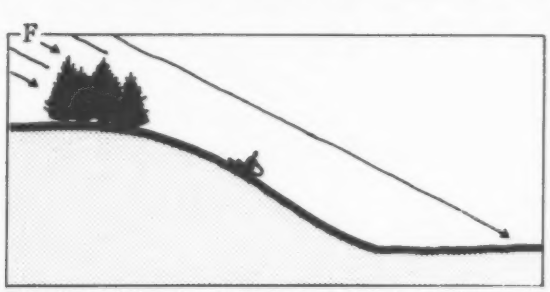


Drainage swale kept clear



Snow storage to accommodate drifting





Skating rinks & toboggan hills shaded by trees

5.1 Introduction

Successful landscape planning for energy efficiency must take account of many factors determined not only by the project at hand but also the priorities and values of society as a whole. It must be a part of the entire design process and consider simultaneously all of the individual influences discussed in previous sections of this report. Whether the end result is to be an outdoor space, a single building or an entire community, the plan must accommodate the climatic factors, conform to the site constraints and meet the overall design objectives. It is expedient to begin this approach with some consideration of the objectives and techniques of site analysis.

5.2 Site Analysis

As societal values change the importance of various factors in the analysis change as well (1). Much of our present concern is for energy conservation, in particular, the energy derived from petroleum. This places a premium on location protected from adverse winds but exposed to radiant energy from the sun (2).

In conducting the analysis, many different techniques are available for data manipulation including the use of overlays, matrices and computer analysis, but all are dependent upon the accumulation of good values for the important variables. To assist in this Table 7 showing the needed climatic data and the site information is helpful. Although such tabulated data does not provide any absolute rating of the value of a particular site, similar tables for two or more may be of great assistance in making a selection of the best location.

5.3 Single Building

A single detached dwelling is important to study because it is a very common element of our built environment and also because it is inherently less

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(1) Costs and Benefits of Environmental Planning Practices, p. 8

(2) Robinette, 1977, p. 70
Site Planning for Solar Access, p. 13

Climatic Data Required	Relevent Site Information Required		
		Influence	Information
1. Sun:	Topography	- angle of incidence of sun's rays - exposure to sun	- slopes: orientation and degree of slope
- orientation: altitude and azimuth			
- quantity: solar radiation and cloud cover	Vegetation	- shade - absorption/reflectivity	- identify extent, major forms, and density of cover
	Surfaces	- absorption/reflectivity	- identify colour and depth of soil - identify type, colour, and extent of hard surfaces (bedrock, paving)
	Existing Development	- shading - absorption/reflectivity	- identify extent of shading - identify colour and texture of exposed materials
2. Wind:	Topography	- wind speed and direction - exposure/shelter	- identify slopes and land forms
- direction, frequency, duration, intensity, consistency/turbulence	Vegetation	- wind speed and direction - exposure/shelter	- identify extent/major forms, and density of cover
	Existing Development	- wind speed, direction, and turbulence - exposure/shelter	- identify forms and associated wind patterns
3. Air Temperature:	Topography	- cold air drainage	- identify valleys, gullies, and plateaux
- maximums, minimums, averages, ranges	Vegetation	- temperature modification	- identify extent, major forms, and density of cover
	Hydrology	- temperature modification	- identify water bodies, wetlands, rivers and streams
4. Humidity	Vegetation	- humidity modification	- identify extent, major forms, and density of cover
- vapour pressure, relative humidity	Hydrology	- humidity modification	- identify water bodies, wetlands, rivers, and streams
5. Precipitation			
a. Dew, Fog, Frost	Topography	- cold air drainage (frost, and dew pockets)	- identify valleys, gullies, and plateaux
- quantity, frequency, duration	Vegetation	- dew/frost shadows - fog catch	- identify extent, major forms, and density of cover
b. Rain	Topography	- drainage patterns	- identify existing drainage patterns
- maximums, minimums, averages - storm frequency and intensity	Surfaces	- quantity and rate of runoff	- identify depth and permeability of soils - identify extent and types of hard surfaces (bedrock and paving)
	Vegetation	- quantity and rate of runoff	- identify extent, major forms, and density of cover
	Hydrology	- water flow and circulation	- identify existing hydrograph: amounts and rates of evapotranspiration, surface runoff, percolation
	Existing Development	- quantity and rate of runoff	- identify existing forms and rates of runoff
C. Snow	Topography	- snow drifting and accumulation	- identify slopes, valleys, gullies and existing drift patterns
- maximums, minimums, averages - storm frequency and intensity	Vegetation	- snow drifting and accumulation	- identify, extent, major forms, and density of cover
	Existing Development	- snow drifting and accumulation - snow storage	- identify existing forms, drift patterns, and snow management strategies

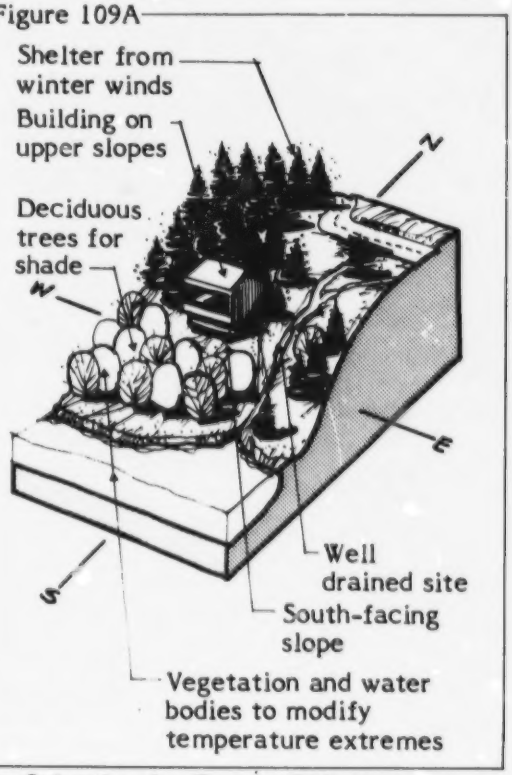
Climatic Data and Site Information

efficient in energy use than a dwelling unit which forms a part of a larger building. It provides an opportunity to consider a wide range of factors as the influence site selection, planning and design. The checklists which follow and the sketches of Figures 109A-D will serve as a reminder of points discussed in more detail in preceding chapters.

5.3.1 Site Selection

- Sites facing southeast, south, or southwest heat up faster during the day and provide opportunities for optimizing the building's orientation to the sun.
- Sites sheltered from winter winds and open to summer breezes are warmer in winter and cooler in summer.
- The air temperature is more consistent on sites near large water bodies or areas of vegetation.
- Sites on mid to upper slopes are warmer than those in the bottoms of valleys or on hilltops.
- Sites on east-west streets provide optimum solar access.
- Sites shaded by deciduous trees are cooler in summer.
- Sites which are well-drained minimize the need for costly drainage systems.

Figure 109A

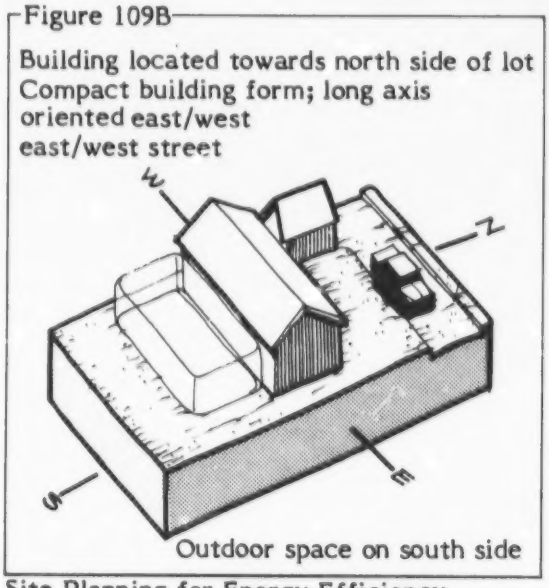


Site Selection for Energy Efficiency

5.3.2 Site Planning

- Building is located towards north side of lot or small site.
- Building form is compact; long axis runs east/west.
- Active zones are located on south sides of building.
- Outdoor use areas are located adjacent to south side of building.
- Southern exposure is maintaned free from obstructions.
- Roads are oriented across winter winds and with summer breezes.

Figure 109B



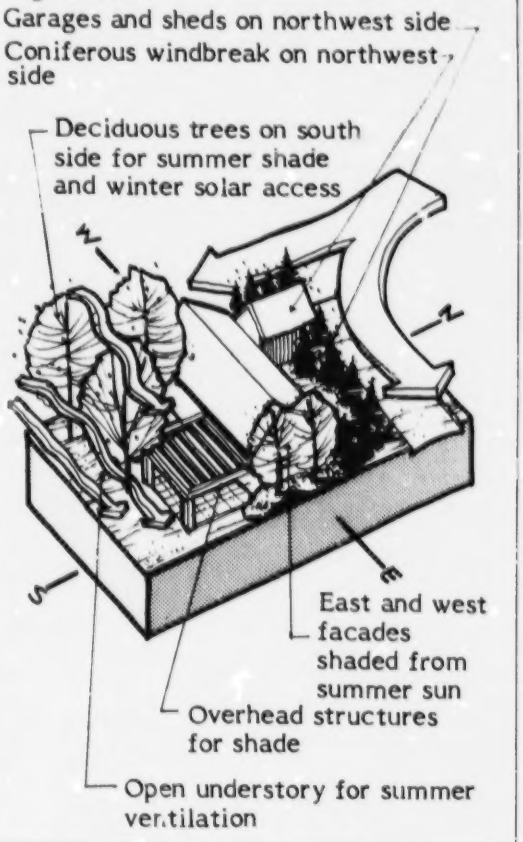
Site Planning for Energy Efficiency

- Large paved surfaces are located to lee of use areas with respect to summer breezes.
- Existing hydrograph is maintained.

5.3.3 Site Design

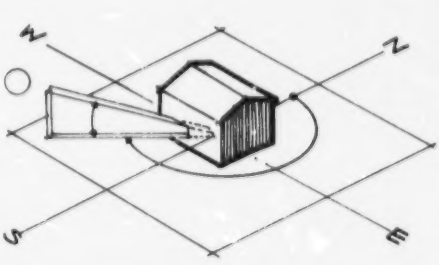
- Deciduous trees on south side provide summer shade and admit winter sun.
- Overhead structures provide shade for outdoor use areas.
- East and west facades are shaded from low-angled sun.
- Outdoor use areas are developed as sun pockets for warmth.
- Light coloured walls or fences reflect sunlight into north windows.
- Light coloured paving on south side reflects winter sunlight into building.
- Dark materials store heat for evening warmth.
- Tree and canopies inhibit outgoing re-radiation.
- Paving is minimized and shaded from sun.
- Windbreaks on the north and northwest sides reduce winter winds (coniferous trees, walls, fences, other buildings).
- Understory of vegetation is cleared to admit summer breezes.
- Snow barriers reduce snow accumulations in high use areas.
- Low use areas are used for snow storage.
- Ponds, lakes, and fountains provide summer cooling and increased humidity.
- Roof decks with soil and planting can add both mass and insulation to buildings.

Figure 109C


Garages and sheds on northwest side
Coniferous windbreak on northwest side
Deciduous trees on south side for summer shade and winter solar access
N
N
S
E
East and west facades shaded from summer sun
Overhead structures for shade
Open understory for summer ventilation

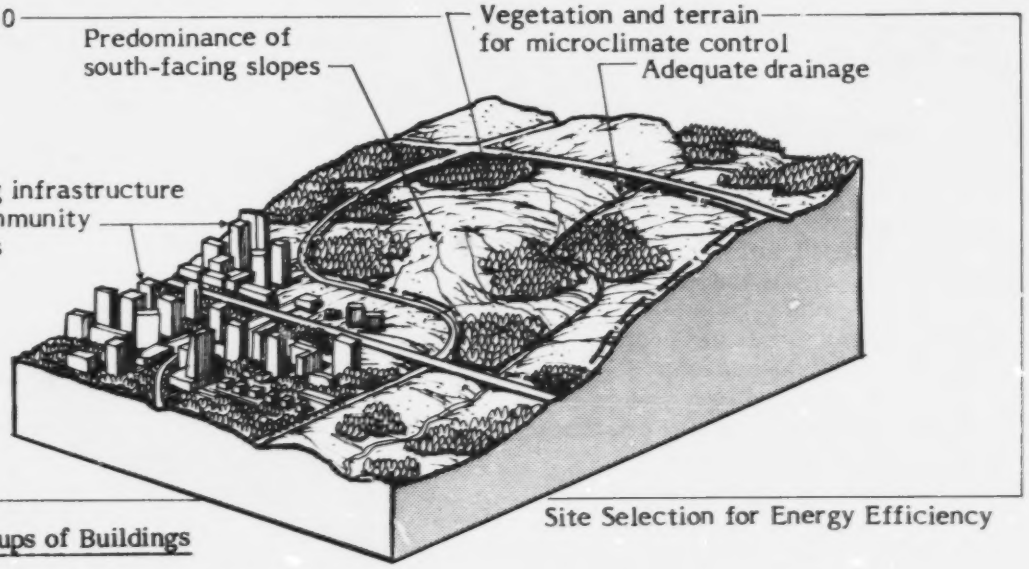
Site Design for Energy Efficiency

Figure 109D



Predictability of sun's movement permits precision design for solar access

Figure 110



Site Selection for Energy Efficiency

5.4 Groups of Buildings

While it is complex, the relationship between community structure and energy efficient landscape planning is important. Two concepts are central to the process, consolidation and integration (1). Consolidation refers to development density; important because energy use tends to decrease as density rises. This comes about for several reasons:

High density implies multi-unit buildings which have reduced exposed areas per dwelling unit.

There are efficiencies of scale in heating and cooling equipment.

Travel times are reduced and public transportaion facilitated.

Cost per person of installing and maintaining roads and utilities is reduced.

Integration refers to the organization of land uses within a community as distinct from segregation in which residential, commercial and industrial areas are separate and frequently remote from one another. An integrated community is energy efficient by reason of:

Shared use of capital intensive facilities.

Reduced travel time and more efficient use of public transporation.

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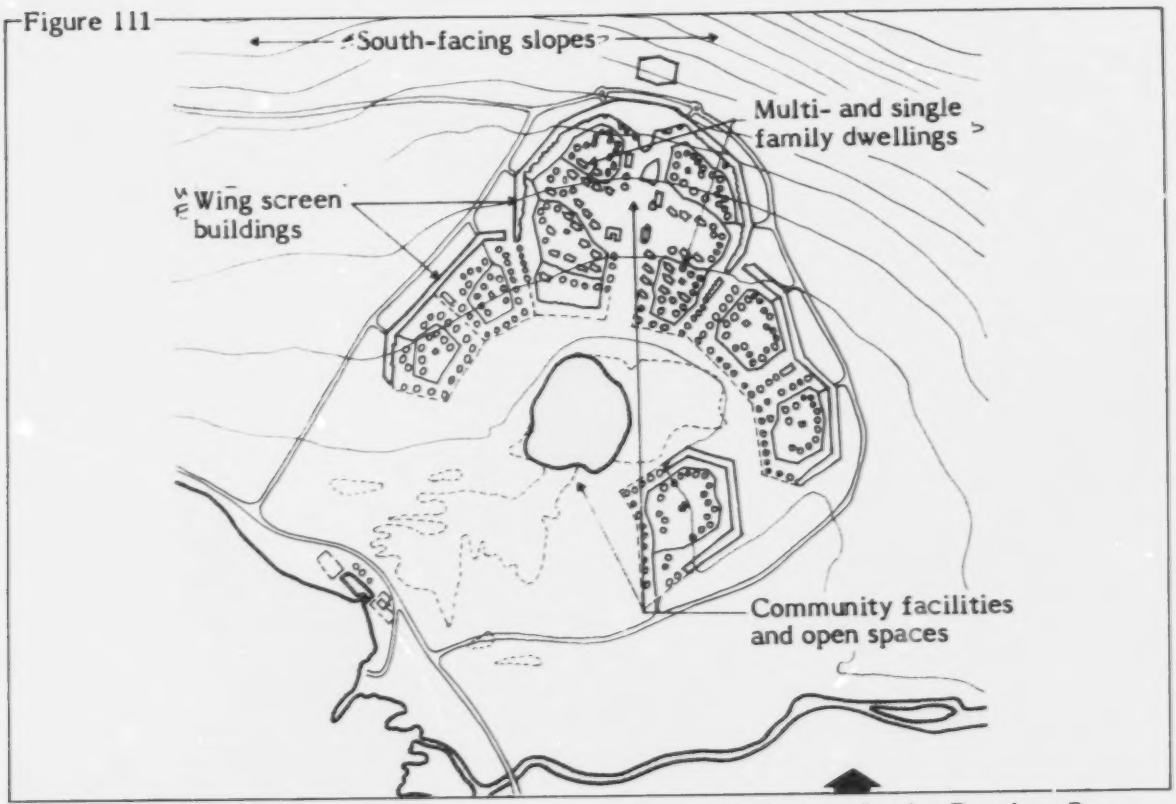
(1) Basic Guidelines for Energy Conservation in Community Planning and Building Design, p. 3

5.4.1 Development of New Northern Communities

Communities in Canada's north require any advantages which they can gain from energy efficient planning to offset the harsh environment and the high cost of fuel. There was not only this challenge, but also the freedom of some of the contraints imposed in more southerly areas when plans were developed for a community of 1200 in Resolute Bay. A sketch of the proposed plan is shown in Figure 111. The principles used here could well be applied in other locations (4). The protection of space from wind by building placement both for recreational use and as extension of interior spaces (5) is typical. These 'wind screen' buildings are planned to protect the entire community by placement at the top of south facing slopes with their own openings facing inward and so far as possible blank walls on the exposed faces (6). Other buildings are

(4) Building in the North, 1976
(5) Culjat, 1975, p. 117
(6) Building in the North, 1976, p. 20

Figure 111

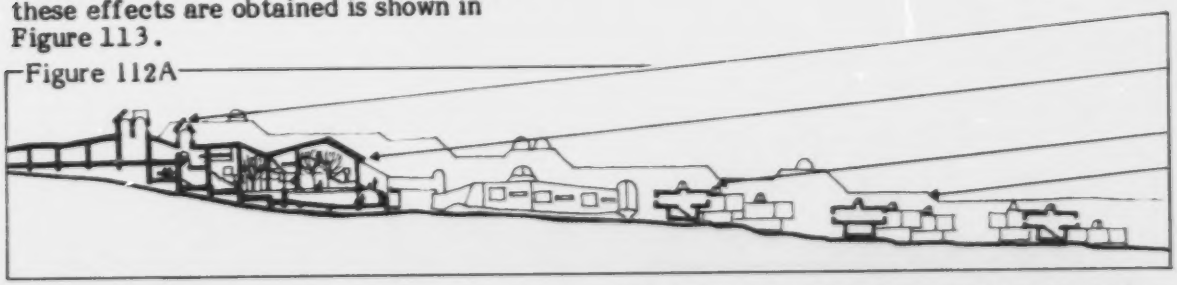


Proposed Community for Resolute Bay
(Source of the following drawings: Culjat, 1975)

located on the slopes so that all receive direct sunlight for as long as any is available as shown in Figure 112.

Wind protection offered by the perimeter building shields patterns of circulation (7) between buildings and from buildings to protected outdoor spaces. These, located on south facing slopes, receive not only direct sunlight but also reflected energy from the facades of adjacent buildings which are designed to maximize this effect. Less well protected spaces intended for general recreation and as transitions to the unprotected environment are expected to be usable for only part of the year (8). The way in which these effects are obtained is shown in Figure 113.

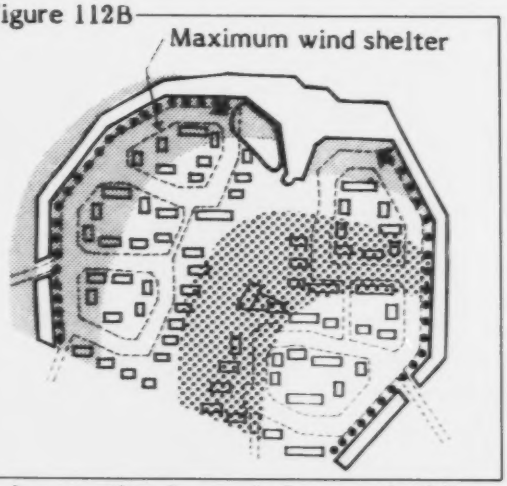
Figure 112A



Sectional view showing provision for solar access to all buildings and major outdoor spaces

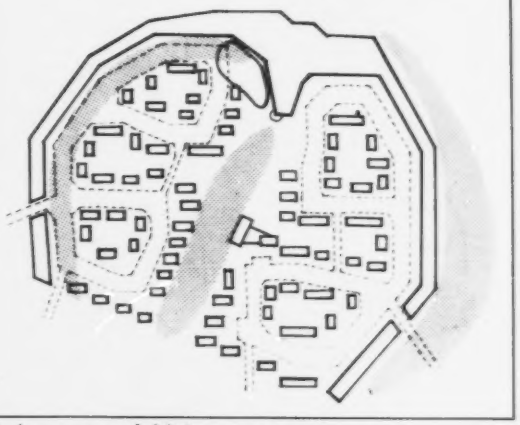
(7) Culjat, 1975, p. 139
(8) Culjat, 1975, p. 209

Figure 112B



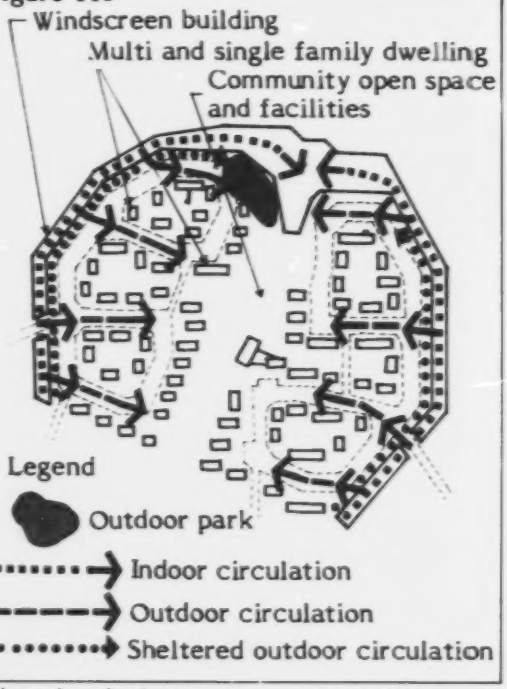
Wind protection from wind screen buildings

Figure 112C



Major snow drifting patterns

Figure 113

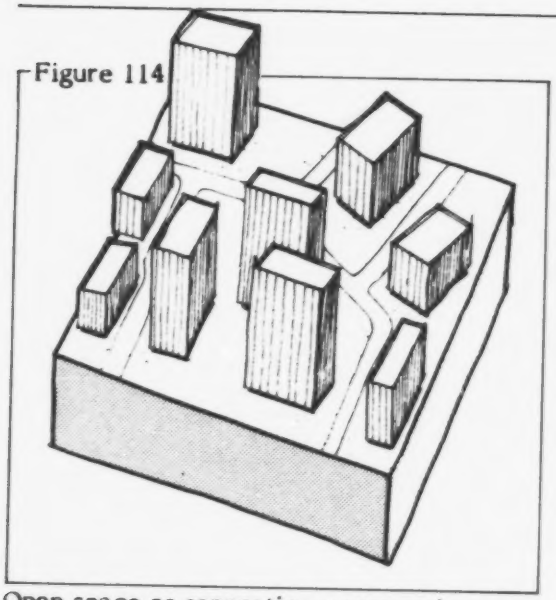


Major circulation routes protected from winter winds

5.5 Open Space Planning

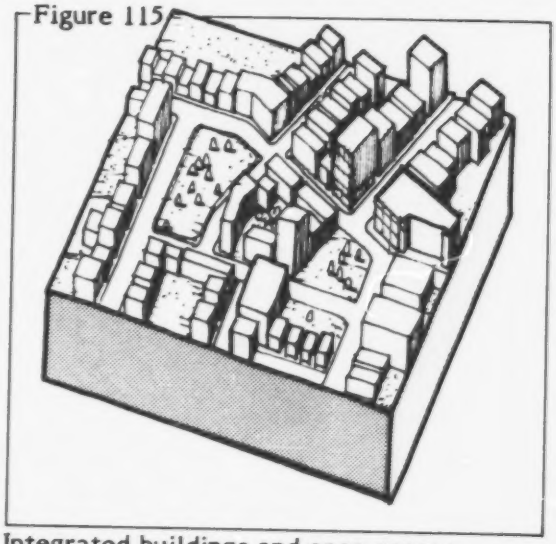
In preceding sections of this report we considered how open spaces can be utilized to reduce energy consumption in the buildings which they surround. In addition to this function, open spaces provide for many recreational uses as well as permitting free movement through an entire community. To select the best sites for building (2) without regard for the needs of open space is to disregard the role which they can play. Figure 114 shows open space treated purely as building set-back and

Figure 114



Open space as separation space and transportation corridors

Figure 115



Integrated buildings and open spaces

transportation corridor while Figure 115 suggests how it may serve not only these functions but others as well. Because different functions create different demands, to design the spaces to provide some range in microclimates will increase their utility. Landscape architects make the distinction between hard and soft open spaces, the former consisting of streets, plazas and paved surfaces while the latter are the parks and playgrounds. They recognize the different roles of each and the different design problems they present.

5.5.1 Hard Open Spaces

Particularly in downtown areas where buildings are large and close to one another, planning for solar access to streets and spaces between buildings is difficult. Even in areas where buildings are smaller, the preference in favour of building over the open space often means that here, too, outdoor space is unusable for much of the year. The importance of extending planning beyond the building site (4) was well illustrated with respect to the city hall in Toronto. Located at the northern edge of the property, it achieved a design goal of providing a sunny protected open space now partially shaded because construction of a 40-storey hotel across the road could not be prevented (5).

(2) Site Planning for Solar Access, p. 46
(4) On Building Downtown, p. 185
(5) On Building Downtown, p. 22

The turbulence of ground level winds around large buildings creates additional problems. Some information can be obtained in advance by wind tunnel testing but many authors feel that cannot predict wind behaviour in full detail (6).

Table 8 shows some typical outdoor activities and the wind speed areas to which each is suited (7).

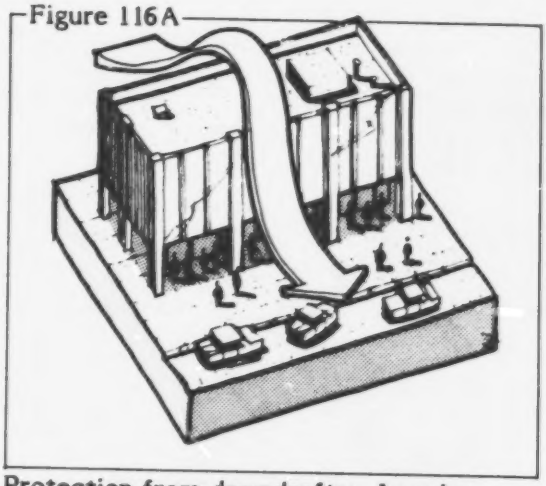
At the scale of detail design, some protection can be offered from downdrafts by arcades as shown in Figure 116A and B while overhead walkways should be located away from corners and areas heavily used by pedestrians.

Table 8

- outdoor restaurants - bandshells - plazas - sitting areas - pedestrian gathering areas	LOCATE IN VERY CALM AREAS
- landscaped parks - strolling areas - areas to be used by aged pedestrians - skating rinks - building entrances	LOCATE IN LOW TO MODERATE WIND SPEED AREAS
- non-pedestrian podiums - mechanical exhause - parking lots - wind speed indicators - mechanical exhausts	MAY BE LOCATED IN MEDIUM WIND SPEED AREAS
- non-pedestrian podiums	MAY BE LOCATED IN HIGH WIND SPEED AREAS

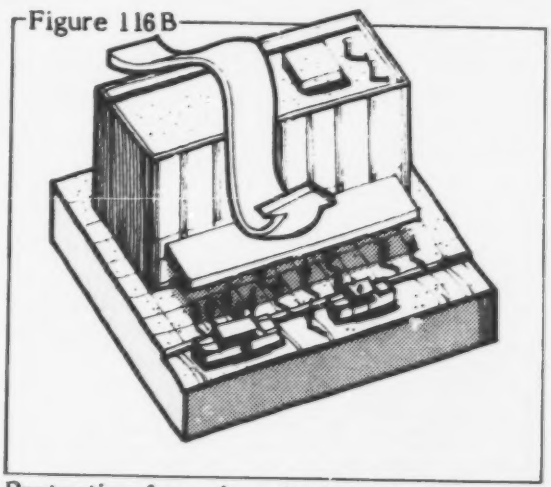
General Requirements for Selected Pedestrian Activities
(Source: Mississauga City Centre - Energy Report)

Figure 116A



Protection from downdrafts: Arcades

Figure 116B



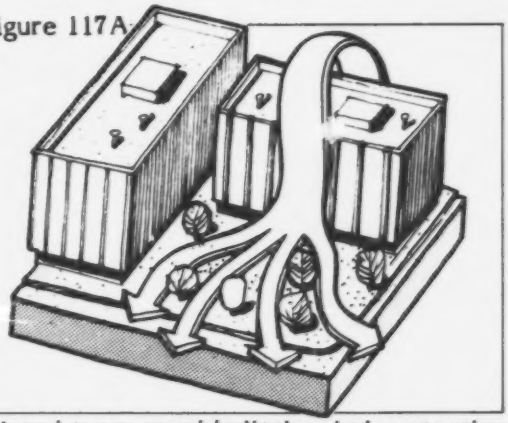
Protection from downdrafts: Overhead structures

(6) On Building Downtown, pp. 40, 190
Mississauga City Centre, Appendix IX

(7) Mississauga City Centre, Appendix IX

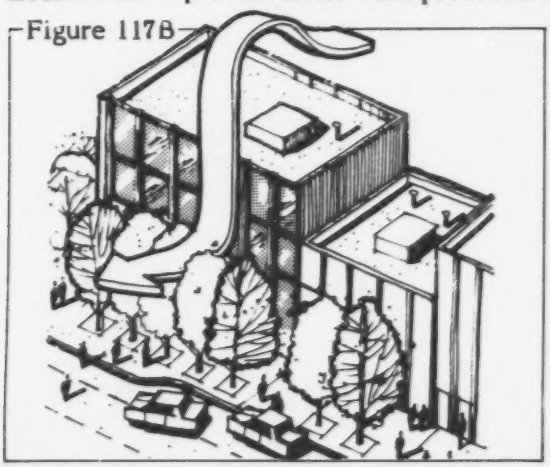
Vegetation, if sufficiently dense and properly located, can help to provide some wind shelter (Figure 117A-C) either by itself (Figure 119A) or in conjunction with other components (Figure 118A-D) (8).

Figure 117A



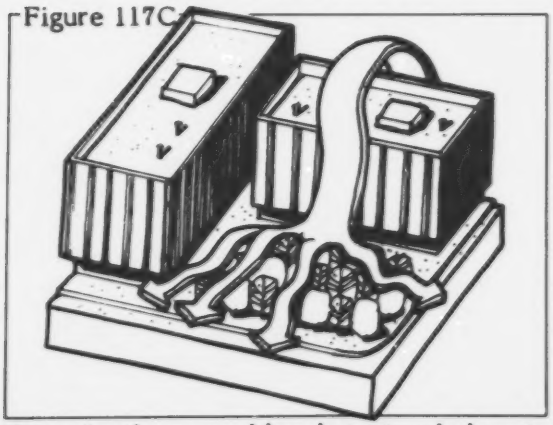
Isolated trees provide little wind protection

Figure 117B



Trees can buffer and reduce downdrafts

Figure 117C



Mass plantings provide adequate wind protection

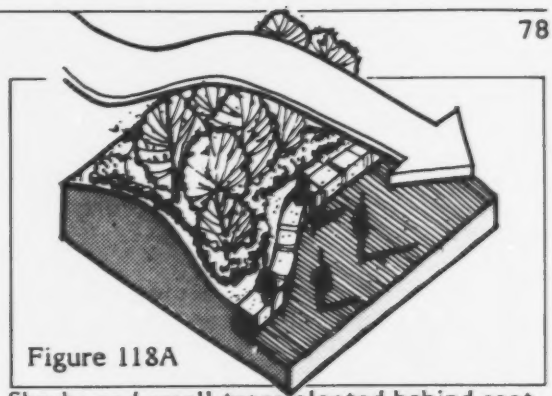
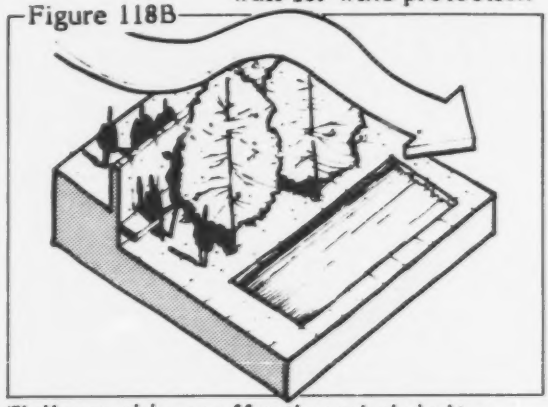


Figure 118A

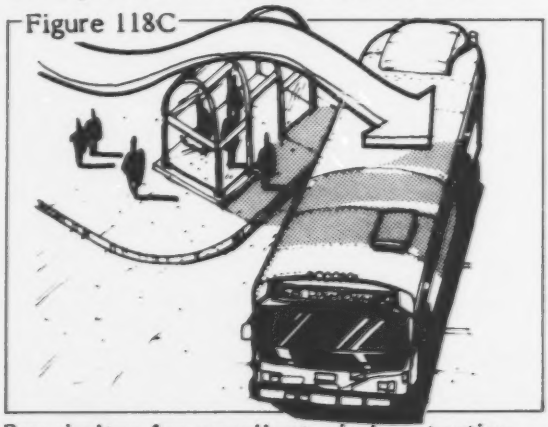
Shrubs and small trees planted behind seat wall for wind protection

Figure 118B



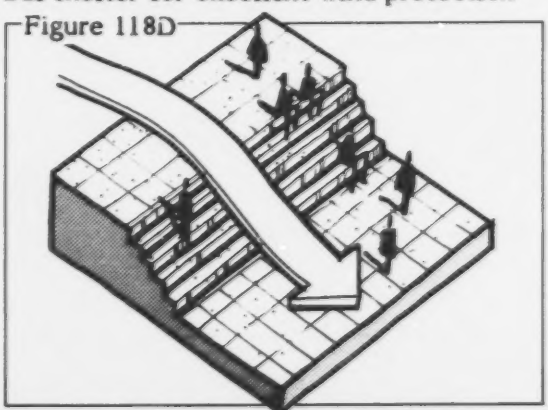
Walls provide an effective wind shelter

Figure 118C



Bus shelter for excellent wind protection

Figure 118D



Steps provide little wind protection

(8) Mississauga City Centre, Appendix IX On Building Downtown, p. 36

While solar heat in hard outdoor spaces is welcome in winter, shade is of more importance in summer. Deciduous trees cannot only protect from direct (9) and indirect (10) radiation as shown in Figures 119A and B but also help to retain heat in the evening as shown in 120C (11).

5.5.2 Soft Open Spaces

Soft open spaces should provide a range of microclimates suitable to the range of activities which they accommodate (12). A distinction should be made between areas used for frequent and primarily non-recreational use and the play areas. The former would include sidewalks and walkways through the area used for communication between activity centres. These essential areas needed daily in all seasons should be designed for solar access and wind protection in the winter and yet be shady and well ventilated in summer.

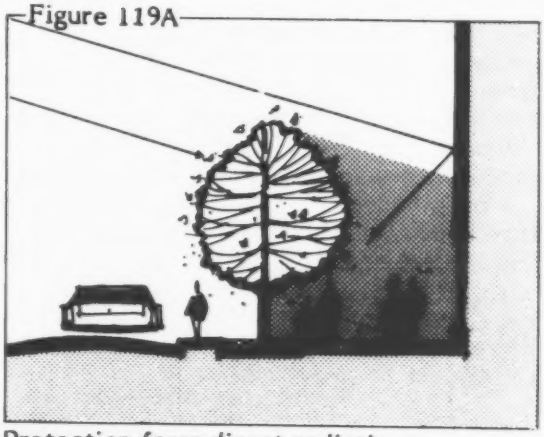
Play areas on the other hand want the greatest range of microclimates possible (13). Players engaging in differing degrees of physical activity will then be able to find locations which are suitable under varying ambient conditions. Thus, the use of the open space will be encouraged for many activities from kite flying to hockey or from picnicking to jogging. By proper use of vegetation and any available topographic relief varied conditions can be created except on the very smallest of sites.

5.5.3 Green Space Systems

A discussion of the contribution of landscape architecture to community designs which are energy efficient would be incomplete without a reminder that we must not overstate our case.

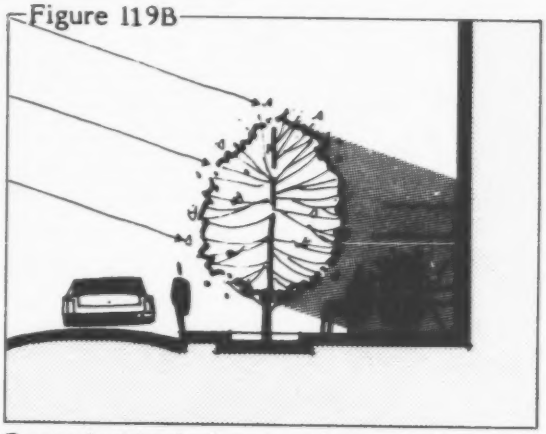
There is little doubt that the trees lining residential streets which shade the roads and sidewalks result in lower summer temperatures (14) in urban areas despite the

Figure 119A



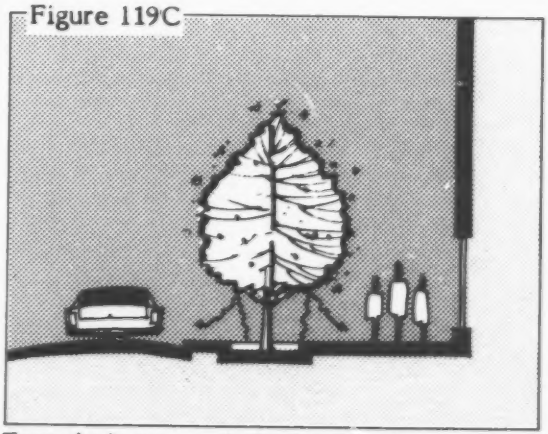
Protection from direct radiation

Figure 119B



Control of both direct radiation and radiated heat

Figure 119C

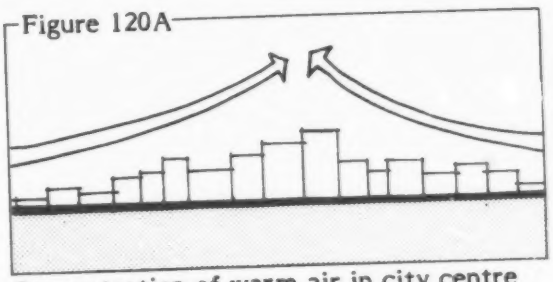


Trees help to retain heat at night

(9) On Building Downtown, p. 23
(10) Herrington, 1975
(11) Federer, 1976; Herrington, 1975; Herrington, 1976
(12) Heisler, 1974; Plumley, 1977
(13) Plumley, 1977; Heisler, 1974
(14) Federer, 1976; Heisler, 1976

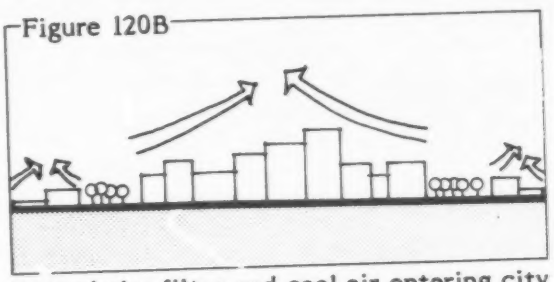
heat absorbing surfaces (15) and the heat escaping from buildings (16). These same trees may make the city atmosphere healthier (17); they certainly make it more pleasant. However, to suggest that a greenbelt around an urban area can provide a constant supply of cool fresh air (18) by the mechanism illustrated in Figure 120is less easy to accept. As the next and final chapter will show the benefits are real and the costs modest, let us make sure that these attributes are reflected in our claims for the art.

Figure 120A



Concentration of warm air in city centre

Figure 120B



Green belts filter and cool air entering city centre

Theoretical Effect of Greenbelts

(15) Federer, 1976
(16) D'Agostino, 1980
(17) Bernatzky, 1977
(18) Bernatzky, 1966, 1977

6.1 Introduction

The determination of costs and benefits of any aspect of environmental design is difficult and imprecise. In addition to the need to forecast future values of economic variables, which is common to all such analyses, dealing quantitatively with environmental concerns would require assigning values to intangibles such as "attractiveness".

Because of these difficulties, it is common to confine the analysis to the factors to which economic values can be assigned in the expectation that some weight can be given to intangibles in the final stages of the decision making process. Two methods are in general use to calculate costs and benefits. The payback period method is simplier but life cycle costing while more complex is more accurate when the data is available to apply it. Since both methods are well treated in the literature, we will not deal with them here but rather discuss some of the factors to be considered and the ways in which numerical values can be estimated.

6.2 Shading

The reduction in energy required for air conditioning when direct solar radiation is blocked may be significant. At Indiana University tests were conducted to determine the cooling effect of shade trees. At an air temperature of 28.8°C the temperature of exposed concrete was 34.2°C while that shaded by a tree was 31.1°C (1).

Air temperature over ground with vegetative cover on a still sunny day was found to be 5.6-7.8°C cooler than over exposed soil and as much as 16.7°C cooler than over asphalt (2).

Tree shaded windows in a test in Miami admitted only a third of as much energy as unshaded ones while tests in Pennsylvania (4) indicated savings in cooling energy up to 75 per cent when mobile homes were shaded by deciduous tress.

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(1) Olgyay, p. 53
(2) Hastings and Crenshaw, p. 1-26
(4) DeWalle, 1980

6.3 Winter Wind Control

Heat loss due to wind is caused by air infiltration and by a reduction in the thickness of the still air film which covers the walls of a building and this reduction varies with wind velocity. It is estimated that a reduction of wind speed from 32 to 8 km/hr can result in a fuel saving of up to 25 per cent (13). A computer simulation study prepared for the Ontario Ministry of Housing (14) estimated energy savings of 19 per cent for a reduction in wind velocity from 24 to 9.6 km/hr.

Tests in Nebraska (6) indicated that wind protection would reduce fuel consumption by 23 per cent and it was suggested that the saving might rise to 30 if there were protection on three sides of the building.

Substantial wind velocity reduction is possible by the use of various forms of windbreak. A wooden fence constructed to silmulate a mature tree barrier was tested at Indiana University. At distances of five times barrier height wind velocities were halved and reduced to 75 per cent at 27 times the height of the fence. In other tests (7) thick belts of trees and shrubs were found to reduce wind velocities by more than 50 per cent for distances up to ten times the height of the windbreak and by 35 per cent out to a distance of 20 times.

Simulation studies at Princeton University showed that wind infiltration in a building could be reduced up to 30 per cent by a 1.7 m wooden fence and by 40 per cent by a single row of evergreens. In combination fence and trees, reduced velocities up to 60 per cent (8).

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(13) Van Havenbeke, 1978
(14) Residential Site Design and Energy Conservation
(6) Olgyay, p. 99
(7) Lynch, p. 74
(8) Mattingly and Peters, p. 30-39

In South Dakota the difference in average heating energy requirements for an exposed and sheltered house were found to be 34 per cent (9), while a row of conifers on the exposed walls of a house in another test (12) produced savings of 23 per cent.

No cost data are offered for any of the above measures but it is obvious in heating requirements claimed.

6.4 Landscape Planning as a Contributor to Energy Efficient Design

It is difficult to single out the part of any one design discipline plays in a field where even overall cost benefit analysis is imprecise. For example, a subdivision planning study (15) found that when the energy costs of six different designs were compared that savings were strongly correlated with density. To achieve high density while preserving attractiveness, convenience, and other desirable aspects no doubt placed severe demands on the landscape planners but it is impossible to decide what share of the credit for the savings should be assigned to their work.

Perhaps as in so many other aspects of life in which intangible values are important we must be satisfied with knowing that the designs which add so much to the attractiveness of our surroundings are functional as well as beautiful.

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(9) Hastings and Crenshaw, pp. 1-5
(12) Residential Site Design and Energy Conservation
(15) Residential Site Design and Energy Conservation

CONCLUSIONS

State of the Art

It is clear from the research that has been conducted to date that appropriate landscape development can result in increased energy efficiency. The energy required to heat and cool buildings can be significantly reduced through judicious site selection, planning and detail design. Moreover, the efficiency of communities can be increased through the planning and design of outdoor spaces which provide reasonable alternatives to energy intensive transportation modes and interior facilities.

However, the research also reinforced the fact that landscape planning for energy efficiency cannot be soley based on the discovery of straightforward technical solutions which can be universally applied across the board. The large number of ways for achieving greater energy efficiency through landscape planning is a direct reflection of a complexity and variability of climate as well as of the diverse forms and use of both natural and built environments. Like all physical design problems, the planning of energy efficient environments requires an in-depth understanding of the problems, the investigation of concepts underlying potential solutions, and the selective and sensitive application of these concepts to the particular conditions characterizing each site and its context.

Moreover, inasmuch as environments are themselves integrated wholes, effective energy efficiency can only be achieved to the extent that landscape planning is considered not as something separate, but as an integral aspect of the total planning and design process. The co-ordination among the various disciplines involved in environmental design is essential and requires that the boundaries now separating and isolating the design disciplines are lowered to all a more fluid exchange of ideas as well as more responsive approaches to problems.

The elimination of the artificial distinction between landscape planning and architecture in particular, would facilitate the primary objective of energy efficient design, that is, the integration of building and site, of natural and built environment. As Brois Culjat (1) argues, there are two ways in which energy efficiency can be achieved. The first method involves the construction of immense, simple buildings with a minimum number of doors and windows. The efficiency of these buildings, which would accommodate all of the communities residential, industrial, and commercial activities, stems from the exponential relationship between volume and surface area of simple forms; as size increased, the volume increases at a much faster rate than the surface area. However, with the decreased surface area per unit volume would result in greatly improved energy efficiency, the inhabitants of these "megabuildings" would risk losing all contact with the exterior environment. Culjat maintains that regular intimate contact with "nature" is a central requirement of all people, but especially of those who live in severe climates. The contact with nature is particularly important when the exterior environment is harsh and inhospitable as it frequently is in Ontario. Culjat proposed that the alternative to huge, multi-function buildings is the development of small buildings which are totally integrated with the surrounding environment. Lacking volume and mass, small buildings must rely for energy efficiency upon their sympathetic relationship with both the site and the local climate. In order to achieve such a relationship between building and site, it is necessary that the built environment be considered as a continuum from interior to exterior environments. It is in this respect that the importance of landscape planning is established, although the role of landscape planning must necessarily be continuous with that of architecture.

Following from this the effectiveness of landscape planning for energy efficiency is clearly related to the stage in the planning process at which it is considered. Although significant energy savings can often be realized through the appropriate development of exterior spaces around buildings, the savings are limited when energy efficiency is relegated to detail design. In order to achieve energy savings of a magnitude which will soon be essential, design criteria for energy efficiency must be given a high priority during the early stage of the planning process. Landscape planning for energy efficiency must be considered in all aspects of the planning process from program development and site selection to site planning and detail design.

Apart from these general considerations regarding the significance and role of landscape planning for energy efficiency, the research indicates certain design directions and approaches which are most appropriate for Ontario. Due to the relatively severe winter climate in Ontario, the most important objective is to reduce the amount of energy required to heat buildings. This can be accomplished by maximizing the heat gained through solar radiation and minimizing the heat lost due to wind infiltration. Because of the predictability of the sun's movement, buildings can be precisely located and oriented and exterior spaces planned so that they receive maximum benefit of the sun's heat. The control of winter winds is, however, much more difficult due to the wind's variability in terms of both direction and velocity. While components like agricultural windbreaks can be effective under some conditions, their value is diminished in built up areas where winds tend to be turbulent and gusting. For locations with turbulent winds, the research indicates that other methods may be effective. These have been discussed in some detail above.

Future Research

Although there is a considerable amount of research concerning climate and its' relationship to energy consumption, the research concerning landscape planning for energy efficiency is at a preliminary stage. While many authors have suggested design principles and techniques, the quantitative analysis necessary to confirm or refute these proposals has as yet to be completed. In particular, there is a need for much more research concerning the application of these principles to the particular climatic and physical features characterizing Ontario. There are a number of specific areas in which research is urgently required.

Costs and Benefits: Much more research is required in order to determine the actual energy savings of landscape elements relative to the cost of construction and maintenance. As discussed above such analyses must necessarily include factors such as the site specific nature of landscape design and the variability of plant materials.

Plant Materials: There is a need for more research concerning the selection and use of plant materials. In particular, research should be conducted to determine the value of various plant species for particular functions including wind shelter, shade, winter solar penetration. Although some of this information is now available, it is not in a form which is usable by planners and landscape architects in Ontario.

Wind Control: In terms of the technical aspects of landscape planning for energy efficiency, the area of research most required concerns wind control in built up areas. Although a considerable amount of research has been conducted into the wind patterns around large buildings, less is known about the influence of plant materials and other landscape elements in controlling turbulent winds. This is particularly true with respect to suburban development.

Large Scale Planning: At present, there is very little known about the modification of regional climates. Although the modifying effects of vegetation, water bodies, terrain, and urban areas are understood, it is not yet clear whether these effects can be deliberately controlled. In particular, research should be conducted into the effects of urban vegetation and greenspace systems.

Land Uses and Building Types: More research is required into the most appropriate landscape planning for land uses and building types other than residential. While it has been established that buildings have particular energy requirements which vary according to use, little is known about matching landscape planning to the energy consumption patterns of specific buildings.

Site Analysis: Although the general principles of site analysis have been investigated to some extent, more specific techniques need to be developed. In particular, methods need to be developed for identifying and measuring micro-climates and the physical features which affect them and for incorporating climatic and site data into the planning process.

Northern Development: Although there have been a number of very interesting proposals made for the development of new northern communities, more research is required into the potential for landscape planning for energy efficiency in this area. In particular, there is a need for investigation into plant materials and construction techniques which are appropriate for Northern Ontario.

Implementation

There usually exists, especially in environmental design, a considerable time lag between research and investigation on the one hand and implementation on the other. This is no less true with respect to landscape planning for energy efficiency. Although there is a need for quantitative analysis, many of the design concepts are very simple and have been employed for a very long time especially in rural and other somewhat isolated areas. In fact, it is only since cheap energy has been readily available that energy efficient design has become the exception rather than the rule. However, the "re-discovery" of energy efficient design has been prompted by the energy crisis and is once again gradually being assigned a higher priority in the design process.

In order to encourage landscape planners, community planners, architects and developers to incorporate energy efficiency into their work, public agencies have begun to publish guidelines for landscape planning. Of those which are applicable to Ontario, The Conservation of Energy in Housing (by Canada Mortgage and Housing Corporation) and the Builder's Guide to Energy Efficiency in New Housing (jointly published by the Ontario Ministry of Energy and the Housing and Urban Development Association of Canada) include short sections which attempt to detail the basic methods and techniques for energy efficiency through landscape planning. Although these guidelines are very simplistic and reflect the preliminary nature of the available research, they do at least acknowledge the importance of the subject.

However, the widespread implementation of design techniques for energy efficiency depends less upon government guidelines than upon both public acceptance of the energy problem as a reality and the initiative of all those who are professionally involved in the development industry. This is especially true with respect to landscape planning for energy efficiency. Although there are many areas in which refinement and confirmation is necessary, there is a considerable amount of research available which can be immediately applied. That energy efficiency can be increased through landscape planning has been demonstrated; rather than waiting for incontestable proof, the available methods and techniques can best be tested through direct application in professional practice.

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